DOCUMENT RESUME

ED 159 068 SE 024 936

TITLE Integrated Pest Management.
INSTITUTION Council on Environmental Quality, Washington, D.C.
PUB DATE Nov 72
NOTE 50p.; Contains occasional marginal legibility
AVAILABLE FROM Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (Stock Number 4111-0010; $0.55)

EDRS PRICE MF-$0.83 HC-$2.06 Plus Postage.
DESCRIPTORS *Agricultural Chemical Occupations; Agricultural Education; *Biology; Ecology; *Environmental Education; *Federal Programs; Field Crops; Inservice Education; *Pesticides; Science Education
IDENTIFIERS *Integrated Pest Control

ABSTRACT

After a brief discussion of the problems of pesticide use and the status of current pest control practices, a definition of integrated pest management is given along with some examples of its successful application, and a description of some of the reasons why the concept has not been applied more widely. The major techniques which can be used as part of an integrated pest management program that are covered include genetic, metabolic, and environmental control methods. Parasites, predators, microbial agents, and sterilization are also discussed. The concluding chapter covers the role of the Federal Government in the development and use of integrated pest management. (Author/BB)

integrated pest management

publications of the
council on environmental quality:

environmental quality—the first annual report of the council on environmental quality

ocean dumping—a national policy

the president's 1971 environmental program

toxic substances

environmental quality—the second annual report of the council on environmental quality

the president's 1972 environmental program

environmental quality—the third annual report of the council on environmental quality

integrated pest management

prepared
by the council on environmental quality
november 1972

preface

The United States, like other nations, faces a dilemma of increasing food production on the one hand and maintaining environmental quality on the other. Pesticide use has contributed to the control of several major pests and has led to increased rates of food and fiber production. But the accumulation of pesticides in the food chain, the possible reduction in the populations of some fish and wildlife, and the potential threat to man's health posed by some pesticides have shown the need to seek new methods of pest control to supplement current practices. Neither the United States nor the world can afford reduced agricultural production, particularly in light of significant projected population increases. Nor can we be complacent about environmental damages and health threats that can occur from pesticide use, especially when pesticides are used improperly.

In the United States, we are dealing with this dilemma in two ways. The President has proposed comprehensive legislation to regulate the use of pesticides. Although this legislation should result in much greater protection to humans and the environment, in the longer run we need to provide more effective and environmentally desirable methods of pest control. This report deals with such methods—collectively known as integrated pest management—which are aimed at continuing pest control with minimum adverse effects on the environment.

Through our examination of integrated pest management, we have found that pest control can be improved, with reduced environmental impact and often at lower costs to the user. Such improvement does not mean the elimination of chemical pesticides. When used properly and only when needed, pesticides will be an important component of integrated pest management programs for years to come.

Last fall, the Council on Environmental Quality began this study of alternative methods of pest control. A number of pest control experts were asked to serve in an advisory capacity and many others were consulted. We would like to thank all of those involved for their assistance in this effort. A list of major contributors is included as an appendix to the report.

Our report focuses on agricultural and forest pests and emphasizes insect control and, to a lesser extent, weed control. Most of the principles discussed in the report apply as well to other types of pest control and to other pests. Research efforts, training programs, and implementation of integrated pest management will have to reflect the entire range of pest control needs and pests in order for this approach to be fully successful.

Chapter I describes the extensive damage associated with pests and the continuing need for pest control. It also contains a brief description of the status of current pest control practices and of some of the unforeseen consequences of pesticides which affect both the environment and the adequacy of pest control.

Chapter II discusses what integrated pest management is, gives some examples of its successful application, and also describes some of the reasons why the concept has not been applied more widely.

The major techniques which can be used as part of an integrated pest management program are described in Chapters III and IV. Chapter III covers genetic, metabolic, and enviromental control methods. Chapter IV deals with parasites, predators, microbial agents, and sterilization.

The concluding chapter covers the role of the Federal Government in the development and use of integrated pest management. It outlines the significant new measures being taken by the Administration to stimulate this approach, from expanded laboratory research to field application and manpower training.

We hope that this report will be widely read not only by the general public but throughout the agricultural community as well.

RUSSELL E. TRAIN, *Chairman*
JOHN A. BUSTERUD
BEATRICE E. WILLARD

a statement from the secretary of agriculture

The pest control policy of the U.S. Department of Agriculture embraces the concept of integrated pest management. The policy of the Department of Agriculture is to practice and encourage the use of those means of effective pest control which provide the least potential hazard to man, his animals, wildlife, and the other components of the natural environment.

A continuing supply of wholesome and nutritious food, assurance of adequate shelter, and protection of the tangible and intangible values of our natural resources are among the most basic requisites of society today. These essentials of life can be maintained only if the destructive pests that threaten them are effectively controlled.

No single method of pest control will always be effective. We must use a variety of control methods selecting the proper method or combination of methods for each situation. Using a variety of control methods offers the best promise of effective pest control and the least potential for adverse effect on the environment.

This publication by the Council on Environmental Quality describes various techniques now available, or in the process of development, that may be used in an integrated system of pest management. I hope that it will be widely read so that the concept of integrated pest management can be more fully understood and used in our unending battle against pests.

EARL L. BUTZ
Secretary of Agriculture

summary

Throughout history man has struggled against pests in order to protect his health and to provide an adequate food supply. In the decade of the 1950's, food crop damage due to pests reached an estimated $14 billion per year in the United States alone. Despite advances in modern chemical pest control, extensive pest damage continues.

Prior to the late nineteenth century, plowing, planting, and watering schedules were the main methods used to control pest levels. Toward the turn of the century and up until the mid-1940's, organic plant derivatives and minerals, such as sulfur and arsenic-containing compounds, were used for pest control. Over the last 3 decades, they have been largely replaced by synthetic chemical pesticides.

Development of synthetic chemical compounds raised the hope that problem pests could be permanently controlled within a decade. But this has not been the case. While the use of chemical pesticides has increased production of food and fiber, it has also resulted in some undesirable side effects. Some pesticides are both persistent in the environment and able to accumulate at progressively higher concentrations up the food chain. This process of biomagnification for an extensively used chemical may cause man and wildlife at the top of the food chain to receive large exposures to the substance simply through ingestion of food.

The current shift away from the use of persistent chemicals has resulted, generally, in the use of more acutely toxic materials. An increase in pesticide poisoning may result from this transition.

In many cases, insect and plant pests have built up resistance to pesticides, requiring application of more and more pesticides—often with diminishing results.

Despite the recent emphasis on chemical pesticides, a number of promising alternative pest control techniques have been used to varying degrees. These involve environmental manipulations or cultural methods (such as changes in planting, plowing, fertilizing, and watering practices), genetic changes (in both crop resistance and pest susceptibility), biological controls (the release of pest predators and parasites), pest-specific diseases and hormones, and pest sterilization. Use of these techniques along with improved methods of applying pesticides may result in reducing the overall need for chemical pesticides.

Integrated pest management is an approach which maximizes natural controls of pest populations. An analysis of potential pest problems must be made. Based upon knowledge of each pest in its environment and its natural enemies, farming practices are modified (such as changes in planting and harvesting schedules) to affect the potential pests adversely and to aid natural enemies of the pests. If available, seed which has been bred to resist the pests should be planted.

Once these preventive measures are taken, the fields are monitored to determine the levels of pests, their natural enemies, and important environmental factors. Only when the threshold level at which significant crop damage from the pest is likely to be exceeded should suppressive measures be taken. If these measures are required, then the most suitable technique or combination of techniques, such as biological controls, use of pest-specific diseases, and even selective use of pesticides, must be chosen to control a pest while causing minimum disruption of its natural enemies. This approach differs markedly from the traditional application of pesticides on a fixed schedule.

A growing pest management industry centered primarily in the Southwest and West has shown that integrated pest management can be both effective and economical. Although evidence of its overall economic advantage is still incomplete, its economic benefit for crops which use relatively large amounts of pesticides is clear. Chapter II of this report gives several dramatic examples of cost reductions achieved through the use of integrated pest management. For crops using less pesticides, the economic advantage is likely to be smaller except where yields are increased by improved pest control. In general, use of the integrated pest management approach should lead to greatly reduced environmental contamination from pesticide use and to many fewer problems with pest resistance and secondary outbreaks while maintaining or improving our current ability to prevent pest damage.

In spite of its many benefits, integrated pest management is still not in widespread use—probably because of a variety of attitudinal factors as well as economic and personnel constraints. Some of the reasons include the farmers' lack of incentive to change pest control practices, the complexity of these new management techniques, fear of crop loss, inadequate information on economic threshold levels, an inadequate supply of trained professionals, and a limited number of fully developed nonchemical or selective chemical control methods.

Development of these alternatives depends upon research and upon knowledge of the pest, including its behavior, metabolism, and the important ecological factors which affect it.

The Federal Government has initiated programs to overcome these obstacles and to encourage the development and use of integrated pest management. These programs were outlined in the President's Environmental Message of February 8, 1972. To aid the development of new techniques, the Department of Agriculture (USDA), the National Science Foundation (NSF), and the Environmental Protection Agency are initiating a new $3.5 million-per-year research and development effort to develop integrated pest management techniques for six major crop systems. The USDA will conduct extensive field tests of promising new methods of detection and control. This program required $800,000 in fiscal year 1972 and involves an expenditure of $2.8 million per year beginning in fiscal year 1973.

To demonstrate the effectiveness of integrated pest management, the President has ordered a review of the more than 3,800 Federal pest control programs to determine which of them may utilize this technique. Further, the USDA is expanding its pilot field scout program to reduce further the volume of pesticides used. This 3-year program, which initially focused on cotton, is being expanded to other crops which use large quantities of pesticides.

In order to expand training of professional integrated pest managers, the Departments of Agriculture and Health, Education, and Welfare are supplementing an existing program in NSF to develop the necessary curriculum and training programs at appropriate academic institutions. The USDA also will cooperate with the States to develop programs in land grant colleges for certification of private professional crop protection specialists.

The Federal Government is also currently developing standards to prevent agricultural workers from receiving hazardous exposures to chemical pesticides.

Integrated pest management holds the promise of better pest control with minimum adverse environmental effects at lower costs to the farmer. But its widespread adoption depends on surmounting a host of technical and attitudinal barriers. The Federal Government can help, but the long-term success of integrated pest management depends upon the States, the universities, the private integrated pest management industry, and ultimately the farmer.

contents

464-590 O - 72 - 2

tables Page

figures

chapter i pest control: promise and problems

Throughout history pests have threatened man's health and his supply of food and fiber. In Biblical days, locust invasions created famines. A fungus disease spread throughout Ireland causing the potato famine early in the 19th century. Later in the century, the Colorado potato beetle ravaged potato crops throughout the United States. During the period 1951–60, agricultural crop losses due to pests reached an estimated $14.3 billion per year in the United States alone. (*65*) Losses of forest and shade trees and damage to wood in storage are estimated at more than $1 billion annually. (*61*)

While man struggles to produce enough food and fiber to meet his current needs, population growth further challenges his future. At the present rate of population increase, it may be necessary to double or triple agricultural production to meet the world's food requirements over the next 2 or 3 decades. (*7*) Forests are similarly threatened.

Worldwide, modern technologies have engendered a new age in agricultural production often called "The Green Revolution." In recent years, man has learned to grow more on less land and to obtain greater yields from each plant. Plant breeding for higher-quality yields, irrigation, improved cultural practices, new pesticides, and fertilizers have all contributed to this revolution. (See Figure 1.)

To sustain these higher yields, better pest

Figure 1
U.S. Harvested Yield per Acre, Corn and Wheat, 1870–1970 (64)

control will be required.* New hybrid varieties of corn and wheat have been planted throughout the world, but while offering higher yields, they are often more susceptible to pest damage. Moreover, the densely planted and genetically uniform stands provide a more favorable environment for pests and diseases. In 1968, the Food and Agriculture Organization of the United Nations reported that increased yields obtained through improved seed varieties, fertilizers, and farming methods were in danger of being destroyed by pests and disease. (60)

Statistics collected by the Department of Agriculture show that losses due to insects and diseases in the United States have increased both absolutely and as a percentage of crop value since the 1940's but that the opposite was true for weeds.

Thus, although man has made great progress in developing more efficient agricultural methods, improved pest control techniques are needed more than ever before.

development of chemical pesticides

Losses due to pests were simply taken for granted before the advent of modern pest control practices. With the trend toward intensive farming, cultivation of specialized crops increased imbalances in nature which provided favorable conditions for pests to multiply.

During the late 19th century, U.S. agriculture, by then a commercial production industry, commonly used naturally derived chemicals to prevent pest damage. These materials are of two types: organic (carbon-based chemicals, usually plant derivatives) and inorganic (noncarbon-containing compounds, predominantly of mineral origin).

Research about the time of World War II demonstrated the pesticidal effectiveness of several synthetic organic compounds. Perhaps the most renowned of these compounds, the insecticide DDT, soon proved useful for controlling a large number of agricultural and forest insect pests.

While cultural practices and crop strains genetically resistant to pest damage continue to be major factors in controlling pest concentrations, the spectacular pest-killing properties of pesticide chemicals have caused farmers and forest managers to rely increasingly on their use. In many cases, the use of pesticidal chemicals has significantly changed farming and for-

*Although not the subject of this report, modern intensive agriculture has also produced social side effects, such as changes in land ownership and in migration from rural to urban areas. Such side effects illustrate both the need for and the complexity of adequate technology assessment.

estry practices. For example, herbicide use often reduces the need for crop cultivation and thus allows closer spacing of planted rows.

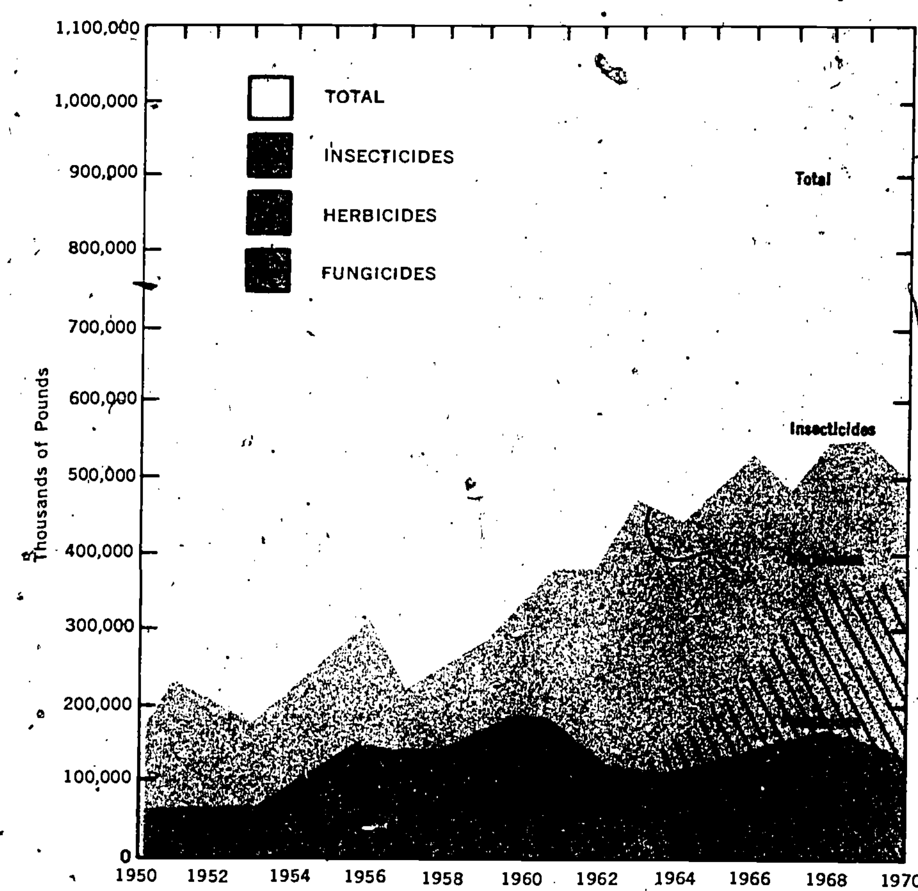
Research initially concentrated on the insecticidal properties of synthetic chemicals, but major advances soon occurred in the development and use of chemicals for the control of weeds, fungi, and nematodes (worm-like soil inhabitants). The use of weed control materials has grown most dramatically in recent years. More progress has been made in the control of plant diseases during the past 30 years than in all of the preceding history of scientific agriculture, due in large part to the development of new fungicides and bactericides. (*61*)

As a result of large-scale testing of chemicals over the years, nearly 1,000 chemicals in over 32,000 pesticide products are currently registered for use. (*61*) Figure 2 shows the production of synthetic organic insecticides, herbicides, and fungicides from 1950 to 1970.

Despite the tremendous growth and impact of pesticide use, data from the most recent survey (1966) conducted by the Department of

Figure 2

U.S. Production of Synthetic Organic Insecticides, Herbicides, and Fungicides (*56*)



Agriculture indicated that of the U.S. acres under agriculture, including hay and pastureland,* only 5 percent was treated with insecticides, 12 percent with herbici[illegible]es, 0.5 percent with fungicides, and only 0.[illegible] percent with nematicides (chemicals for k[illegible] worm-like, soil-inhabiting pests). (*67*) The percentages would probably be greater today, especially for herbicides.

The extent of pesticide use depends heavily on crop and regional considerations. For example, cotton and corn accounted for almost two-thirds of all insecticide use, and corn alone accounted for 41 percent of all herbicides applied in agriculture. Despite the fact that cotton accounts for almost one-half the agricultural use of insecticides, an estimated 46 percent of the total cotton acreage received no insecticide treatments. (*66*, *67*) (See Table 1.)

*Of the 891,000,000 U.S. acres under agriculture, approximately 540,000,000 are hay and pastureland which receive some, but a small fraction of, the total pesticides used.

contamination of the environment

Pesticides have provided control of many major agricultural and forest pests, but adverse environmental effects have resulted in a reevaluation of some of them, especially insecticides and, to a lesser extent, herbicides. The effects of most concern are persistence, biomagnification, and toxicity to nontarget organisms.

Persistence—the ability of a substance to retain its chemical identity and biological activity in the environment for long periods of time—is considered desirable for continued control, but it also causes some environmental problems. If a chemical is persistent—for example, DDT or Mirex—its continued use will result in accumulation in the environment until an equilibrium is reached. The maximum level of accumulation of a chemical depends upon its degradability and the rate at which it is introduced into the environment.

Table 1

Pesticide Use on Several Agricultural Crops in the United States (*46*)

Crops	Insecticides		Herbicides		Fungicides		Crop acres as a percent of total agricultural acres
	Crop acres treated (percent)	Amount of agricultural insecticides used (percent)	Crop acres treated (percent)	Amount of agricultural herbicides used (percent)	Crop acres treated (percent)	Amount of agricultural fungicides used (percent)	
Nonfood	1	50	0.5	NA	0.5	NA	1.26
Cotton	54	47	52	6	2	1	1.15
Tobacco	81	3	2	NA	7	NA	0.11
Food	4	NA	11.5	NA	0.5	NA	98.74
Field crops	NA	NA	NA	NA	NA	19	NA
Corn	33	17	57	41	2	NA	7.43
Peanuts	70	NA	63	3	35	4	0.16
Rice	10	NA	52	2	0	NA	0.22
Wheat	2	NA	28	7	0.5	NA	6.11
Soybeans	4	2	37	9	0.5	NA	4.19
Pasture, hay, and range	0.5	3	1	9	0	NA	68.40
Vegetables	NA	8	NA	5	NA	25	NA
Potatoes	89	NA	59	NA	24	12	0.16
Fruit	NA	13	NA	NA	NA	NA	NA
Apples	92	6	16	NA	72	38	0.07
Citrus	97	2	29	NA	73	13	0.08
All crops	5	[1] 54	12	[1] 36	0.5	[1] 10	NA

[1] Percent of total agricultural pesticides.
NA = Not available.

A perisistent chemical may concentrate in animals or plants and thus enter the food chain of both man and wildlife. If a chemical is used extensively and is biomagnified, so that concentrations build up in the food chain, man and wildlife at the top of the food chain may receive a large exposure to the substance simply through ingestion of food. An example of increasing concentrations of some chlorinated hydrocarbons due to biomagnification is given in Table 2.

Biomagnification and persistence are a particular source of concern when a chemical is capable of causing biological effects, e.g., if it is acutely toxic, carcinogenic (cancer-causing), teratogenic (causing birth defects), or mutagenic (causing genetic alterations) or if it is capable of causing other chronically toxic conditions.

Table 2

Residual Concentrations of Chlorinated Hydrocarbons in Lake Michigan *(32)*

Medium	Residues (in parts per million)
Bottom sediments	0.0085
Small invertebrates	0.41
Fishes	3.0–8.0
Herring gulls	3177

Persistence, biomagnification, and toxicity have been the basis for challenging the use of a number of pesticides. It is now clear that potential environmental effects must be weighed heavily in the design of new chemical pesticides.

Concern over the environmental effects of some persistent chemicals with low acute toxicity is resulting in increased use of substitutes that are less persistent but often more acutely toxic. One consequence may be an increase in the number of human poisonings resulting not only from accidents and mishandling but also from the exposure of field workers to contaminated surfaces such as sprayed foliage.

ecological disruptions

Two other important side effects of pesticides are the development of pests resistant to one or more chemicals and the adverse effects of pesticides on natural pest enemies. Although not direct hazards to health (except for resistant vectors of disease), these factors are of great environmental and agricultural concern.

The ability of pests to develop resistance to pesticides dramatically demonstrates a form of microevolution. The susceptible pests are killed, leaving only those that are genetically resistant. Resistant individuals constitute an increasingly large part of the pest population and pass their resistance on to future populations. If all susceptible pests were killed by a pesticide, an entire population would be resistant.

By 1944, some populations of 44 insect species were known to have developed resistance to various insecticides. Current estimates place the figure somewhere over 230, half of which are of agricultural importance. *(13, 33)* As more chemicals become useless against certain species, the problems of pest control increase concomitantly. Populations of some insect pests have now developed such high levels of resistance to all insecticides registered for use that substitute materials are no longer available and insecticidal control is not recommended. For example, the soybean looper (*Pseudoplusia includens*), a serious insect pest, can no longer be controlled with any insecticide registered for use on the soybean. *(42)*

Similarly, the resistance of some mosquitoes, including the malarial species, has been building up. In Central America, where public health authorities have been combating malaria by spraying insecticides inside houses, mosquito resistance to dieldrin was first encountered in 1958. It was found that the long and intensive use of agricultural pesticides in Central America caused insecticide resistance in *Anopheles albimanus*, the principal malaria vector of the

area. It was subsequently discovered that the mosquitoes began to exhibit resistance not only to dieldrin but also to DDT (like dieldrin, an organochlorine compound), malathion (an organophosphate), and propoxur (a carbamate)—all the insecticides currently available for malarial mosquitoes. (*14*)

In the Cañete Valley, in Peru, cotton insects were controlled with arsenical and nicotine sulfate prior to 1949. The average annual yield of cotton was 470 pounds per acre. A heavy outbreak of cotton bollworm and aphids occurred in 1949, decreasing yield to 326 pounds per acre. From 1949 to 1956 growers relied heavily on DDT, BHC (benzenehexachloride), and toxaphene; they also changed cultural practices and varieties grown. Initially, cotton yields nearly doubled. However, the beneficial insect populations were decimated, and one by one the insecticides became ineffective as resistance to them developed. In spite of increased applications, pest insects became rampant in the fields, and the 1955–56 season ended in an economic disaster. Subsequently, an integrated pest management program was introduced, and yields are now averaging more than 700 pounds per acre. (*54, 61*)

Although extreme, these cases indicate a serious problem. Fortunately, resistance has not proceeded as rapidly and completely in all of the major insect pest species. However, it does appear to be perilously near in some of the most important insects in the United States—the boll weevil (a major cotton pest), bollworm (a pest on corn, cotton, and tomatoes), tobacco budworm, sugarcane borer, and rice water weevil. (*42*) A serious outcome of the resistance phenomenon is that when it appears, no satisfactory pesticide substitute may be available.

Resistance has not yet become a problem in weed control, probably because of the slower reproduction rate of weeds than of insects. Often, what appears to be resistance in a plant species may actually be the replacement of a spider mites, or thrips results in the reduction species by one that is relatively less susceptible to the herbicide used.

The apparent ineffectiveness of a pesticide does not necessarily indicate pest resistance. Pest control effectiveness can also be reduced by the destruction of natural control systems. Only a minute fraction of the total number of insects and plants in the environment is pests. When at normal population densities, most insects and plants pose no threat to cultivated crops, and many are important to the health and stability of the environment because they control other potentially damaging species.

Many synthetic chemical pesticides in use today have broad-spectrum effects, that is, they are lethal to a wide range of organisms, including beneficial competitors, predators, and parasites of the target pest. When populations of insect, nematode, and disease pests are drastically reduced, their natural enemies are generally even more severely affected. A resurgence in the pest population can then occur, with consequent increased damage to the crop. As an example, parathion applied to cole crops (e.g., cabbage and broccoli) may reduce the number of predacious or parasitic insects by 95 percent while reducing the pest species by 10 percent or less. (*69*) Even when the natural enemies are not killed, temporary elimination of their hosts can cause them to emigrate, leaving the crop fields vulnerable to the return of the pest species. Thus, ill-chosen pesticides or ill-timed application can cause proliferation or continuation of a pest infestation.

Sometimes use of broad-spectrum pesticides causes insects which were controlled naturally to increase in number to such an extent that they become pests. This occurs because the insects' natural enemies are killed by the pesticide. Hence, an insect can be made a pest by improper use of pesticides.

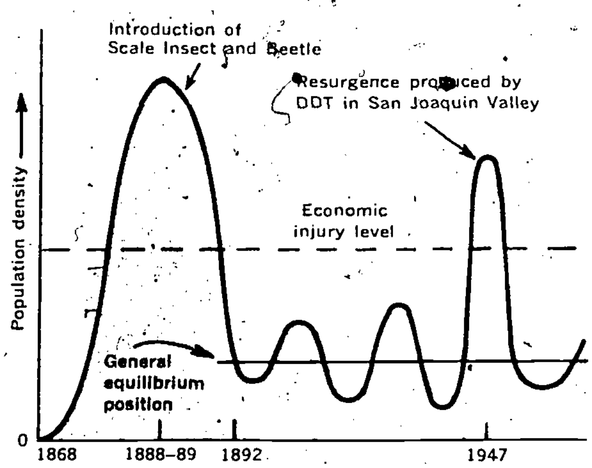
Secondary pest problems often occur in cotton. Early season treatment for lygus, aphids, of many beneficial insects. Thus, later treatment for bollworm (*Heliothis zea*), which thrives in a predator-free environment, is required.

The ladybug, *Vedalia*, was introduced into California from Australia because it preyed extensively on a major citrus scale pest. For 60 years this beetle provided effective control in citrus groves. Yet when DDT was used for insect control in 1946, the number of ladybugs was greatly reduced and the scale problem reappeared. Upon the withdrawal of DDT, control was again established, although not for 3 years in some groves. (*50*) (See Figure 3.)

Sometimes a carefully supervised and timed insecticide application can kill pests without decimating the pests' natural enemies. The host insects occasionally can be killed at a time in the parasites' life cycle when they are least susceptible, for example, while the parasite occupies the body of the pest. (*20*) In such cases, proper timing of pesticide applications may allow for continued partial control of a pest population by maintaining parasite populations.

Figure 3

A History of Scale on California Citrus *(50)*



Other examples of ecological interactions that affect pest management can be cited. Herbicides may increase or decrease insect pest problems by altering the habitat of the pest or its natural enemies. Some pesticides temporarily alter soil fertility and the availability of plant nutrients by killing or inhibiting the activity of soil micro-organisms. (*61*) The sequence in which crops are planted in an area can affect the level of important nematodes, insects, or disease incidence. More generally, changes in tillage practices, in water management, in fertilization, and in other crop production activities can alter the agro-ecosystem sufficiently to affect significantly the average densities of pests.

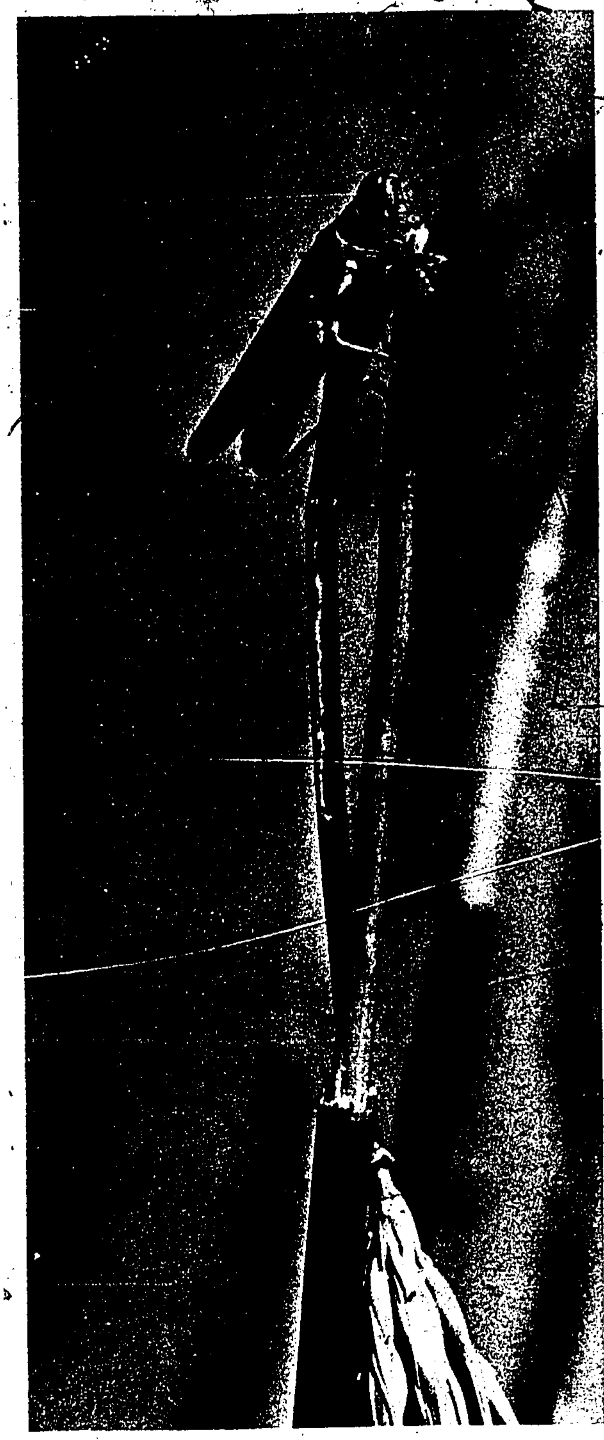
More selective chemicals and application techniques are needed to minimize the chances of ecological disruptions when applications are required. Widespread use of broad-spectrum pesticides, particularly insecticides, often leads to development of resistant pests and to disruption of natural control systems, creating more problems than are solved and adding considerable expense for the user. If the natural control system is badly disrupted, damage may occur until the natural equilibrium is restored.

It would seem that the best way to reduce pesticide problems is to eradicate our major agricultural and forest pests. Only under rare circumstances, however, is complete pest elimination possible. In general, pest eradication with chemicals is difficult if not impossible with current technology. And even if feasible, in most cases the costs would be prohibitive. One of the few circumstances in which an eradication attempt with pesticides may be justified, however, is to prevent the spread of an extremely localized outbreak of a pest of foreign origin. (Despite the efforts of quarantine officials, new and dangerous pests may be accidentally introduced.)

summary

The need for adequate pest control has never been greater than at present. The use of some pesticides, however, has resulted in unintended side effects which either create environmental problems or reduce their own effectiveness. Not all farms and forests are experiencing these problems, and they need not. When used at the right time and in the right way, pesticides can be effective for years to come. Even some non-selective pesticides, when properly used, are likely to play an important, continuing role in effective pest control.

Pest control methods can be used to improve control effectiveness, minimize adverse environmental impacts, and reduce overall control costs. Chapter II describes the nature of integrated pest management. The techniques which can be utilized in applying integrated pest management are discussed in Chapters III and IV.



chapter ii integrated pest management

Integrated pest management is an approach that employs a combination of techniques to control the wide variety of potential pests that may threaten crops. It involves maximum reliance on natural pest population controls, along with a combination of techniques that may contribute to suppression—cultural methods, pest-specific diseases, resistant crop varieties, sterile insects, attractants, augmentation of parasites or predators, or chemical pesticides as needed. A pest management system is not simply biological control or the use of any single technique. Rather, it is an integrated and comprehensive approach to the use of various control methods that takes into account the role of all kinds of pests in their environment, possible interrelationships among the pests, and other factors.

Components of a control program will vary with the type of pest, the nature of the crop, and the environment in which it exists. For example, cultural practices involving early crop maturity, harvesting, and destruction of cotton stalks may be an important and practical aid to boll weevil or pink bollworm control in Southern regions, but these same practices would contribute much less in Northern cotton-growing areas.

Sometimes pest management is confused with organic gardening, a method that does not use synthetic chemicals. Although in many cases synthetic chemicals are not used on a crop during a given season, the purpose of integrated pest management is not to avoid the use of chemicals but to use the most effective and en-

vironmentally sound pest control technique or combination of techniques for long-range pest control.

The three main components of an integrated pest management program are: maximizing existing natural controls, predominantly by cultural methods, to prevent the buildup of pests; monitoring the concentration of pests and natural control factors present to determine the need for further measures; and using the most appropriate technique or combination of pest suppression techniques, only when necessary, to prevent economic damage to the crop.

As will be demonstrated by later examples, crops under integrated pest management need not produce lower-quantity or -quality yields. In fact, both the quantity and quality may be noticeably improved.

With careful monitoring, disruption of the ecology can be minimized. Because most crops tolerate varying levels of pest populations, applying pesticides or taking other action is not necessary until it is apparent that these levels will be exceeded. Control measures are necessary only when a pest has reached or is rapidly approaching an economically damaging level and there are indications that natural control mechanisms cannot prevent damage. Only through monitoring and knowledge of economic injury levels can the real need for pest control be determined.

Approximate economic thresholds have been established for some of our major crops. But thresholds need to be ascertained for a great many more crops, pests, and physical conditions. Economic threshold levels may vary from crop to crop and from area to area and are dependent to some extent upon rainfall and other weather conditions. Further, economic threshold levels will vary during the course of development of a crop. It is expected that threshold data will have to be modified as farming practices change from year to year.

The economic threshold will tell the farmer or crop protection specialist the level of pests that can be tolerated without significantly damaging the crop. Monitoring of pest populations and natural controlling factors can establish the need, or the lack of need, for control measures.

Population assessment is achieved in a variety of ways, depending upon the crop and the types of pests involved. For example, some of our major insect pests may be monitored by traps baited with natural or synthetic lures or by light traps. It is likely that this technique will be used to a greater extent as research progresses. However, the most common method consists of field surveys conducted by pest control scouts, using monitoring techniques that have been developed for many of our major pests.

Field scouts survey the types and concentrations of beneficial insects, other natural enemies, and important physical and climatic conditions in an area. An experienced crop protection specialist can judge from these data the need for action to mitigate developing pest problems.

The benefits of using field scouts in supervised pest control programs, demonstrated on a small scale for several years in many cotton-producing States, are being further demonstrated by two cooperative Federal-State projects initiated in 1971 by the U.S. Department of Agriculture (USDA). These projects involve cotton in Arizona and the Southeastern United States and tobacco in North and South Carolina. A scout, usually of high school or college age and with some knowledge of entomology, is trained to identify and measure detrimental and beneficial insect levels. Each scout covers about 1,000 to 2,000 acres. He collects data and reports them to an agricultural extension agent who compiles the results. The agent then advises the farmer on what types of controls, if any, are necessary.

The use of scouts has resulted in some dramatic benefits and changes in pest control practices. The money saved from reduced insecticide use more than compensated for the cost of the

field monitoring. In the cotton program, for example, the \$1.00 to \$1.50 per acre cost for using scouts resulted in a large reduction of total pest control costs. Overall, it saved the farmers in the program more than \$2.76 million on 220,000 acres (*62*), or \$12.50 per acre less than the cost of the average chemical controls used on cotton. The greatest savings occurred where pesticides were previously applied routinely throughout the growing season, without regard to pest population levels. Average yields per acre actually increased from this program.

Although surveillance is used to detect the buildup of pests, every effort should be made to prevent elevated pest levels from occurring in the first place. Environmental manipulations and resistant crop varieties can prevent such pest buildups. Changes in fertilizing, planting, and irrigating schedules can create conditions unfavorable to a pest. Use of ground cover crops and similar methods can often produce a more favorable environment for pest predators and parasites. These measures maximize the existing natural control system, the key to good pest management.

When surveillance shows that a pest population is rising to damaging levels despite measures taken to foster the natural control system, steps must be taken to prevent crop injury. Depending upon the crop, pest, geographical location, season, weather, and a variety of other factors, one or more techniques can be employed. In the interest of long-range pest control, the method selected should create minimal ecological disruption. Only when pest populations are near economic threshold levels—despite all efforts to control them—should one use methods, such as the broadcast use of a nonselective pesticide, that could disrupt the natural ecological control systems. When disruptive methods are used, care should be taken to restore the natural equilibrium as quickly as possible.

It is becoming apparent that ecological controls, such as those provided by naturally occurring predators, parasites, bacteria, and viruses, are vital to the reduction of pest problems. Any significant decrease in the levels of these beneficial controls can cause other plant and animal species to increase to damaging levels. It is therefore unwise to rely on any method that will disrupt the natural control system even temporarily unless there is great certainty that the target pest can be permanently eradicated or unless other alternatives fail. Methods for controlling pests should either foster the naturally occurring controls or be very specific in their action against the pests. Applications of pesticides often do not meet these criteria because of their effects on nontarget species.

The general concept of integrated pest management—based on maximizing existing natural controlling factors, on monitoring pests and natural enemy conditions, and on using pest suppression measures only if and when needed—is a sound one that should form the basis for dealing with a wide array of agricultural pests. Enough information is now available on most major crop pests and on methods for their control that immediate and substantial progress should be possible in maintaining pest levels below economically damaging levels without severe environmental consequences. Therefore, it is important to continue to press forward in the implementation of integrated pest management systems on as many crops as possible. The development of new control methods and improvements in the integration of various techniques can be expected as research progresses and as we profit from experience.

applications

Experience with integrated pest management is limited. It has been practiced in scattered locations throughout the United States and to a lesser extent in other parts of the world, but

only a few efforts have been conducted on a large scale.

The initial success of USDA programs was mentioned in Chapter I. In addition, successful programs based heavily on field surveillance are currently being undertaken on apples in the State of Washington and in Nova Scotia. In the Annapolis Valley of Nova Scotia, a majority of the apple growers have used a program of integrated pest management since the late 1950's. (*16*) These efforts show that significant improvements can be effected through the use of field surveillance by adequately trained pest managers.

An integrated pest management service industry has developed in California and parts of Arizona and Texas. Nearly 30 small companies sell their integrated pest management services on a per-acre basis. The viability of this small but expanding industry is a measure of its potential. The California Farm Bureau found that cotton, citrus, and grape farmers using these private integrated pest management firms reaped increased net profits (before taxes) of 22 percent. (*58*)

The use of integrated insect management on grapes in the Delano, Calif., area resulted in lower pest control costs. Conventional insect control on grapes in the area involved two applications of Zolone (for leafhopper and Pacific mite) and an application of Parathion (for grape mealybug and omnivorous leafroller). Under an integrated insect management program, insect populations were monitored. When treatment was necessary, a combination of predator release and chemicals kept pest levels down. The new program resulted in yields comparable to conventional control at a cost of but $16 per acre, compared to $48 per acre for the conventional control. This threefold savings in control costs also resulted in an overall increase of 7.3 percent in net income. (*58*)

Similar results have been obtained in groves of Valencia oranges. Depending on local pest conditions encountered by the grower, the cost per acre for integrated pest control ranged from $45 to $54 in Tulare County, Calif., compared to traditional pest and disease control costs of approximately $100. This represents about a twofold savings in pest control costs and an 11.2 percent saving in overall costs. (*58*)

Another example of integrated insect management involves 600 acres of tomatoes near Los Banos, Calif. Although spraying was conducted 4 or 5 times each season, at a cost of about $20 to $30 per acre, damage from the fruitworm continued. An integrated insect management service was able to decrease costs to between $8 and $10 an acre with effective control—nearly a threefold reduction in insect control costs. No spraying whatsoever was necessary in the second year of the program, and during a total 4-year period, only 10 percent of the tomato acreage needed any pesticide treatment. (*51*)

Although evidence of the overall economic advantage of integrated pest management is still incomplete, it seems reasonably well established for crops such as cotton, apples, and citrus, which currently use relatively large amounts of pesticides to control pests. For crops using less pesticides, the economic incentive is likely to be smaller except where yields are increased by improved pest control. For the latter commodities, no firm economic conclusions can yet be made because of limited experience with integrated pest management on these crops.

obstacles to be overcome

Despite its many benefits, the integrated pest management approach is still not in widespread use—probably because of a variety of attitudinal factors as well as economic and personnel constraints. Some of the reasons include the farmers' lack of incentive to change pest control practices, the complexity of these new man-

-agement techniques, fear of crop loss, inadequate information on economic threshold levels for various pests, an inadequate supply of suitably trained professionals, and a limited number of fully developed nonchemical control methods.

One of the most important reasons for the limited use of integrated pest management is the absence of any impetus for the farmer to change current practices. He is accustomed to using pesticides, has generally not encountered sufficient problems and side effects to warrant his seeking an alternative approach, and is a recipient of free advice from representatives of the chemical industry.

The lack of experience with integrated pest management may lead farmers to fear crop loss or to have a sense of insecurity about unknown, untried, or more complex methods of pest control. Most nonchemical techniques are more sophisticated than use of pesticides, and rarely can they bring about the immediate pest reductions obtainable with chemicals. Moreover, many farms and forests are operated on rigid timetables, and regular application of pesticides may be more convenient than a pest management program dictated by field conditions. Because of these factors, it will be necessary for the economic benefits of integrated pest management to be demonstrated to the farmer in the field, as is now being done in scattered locations. But even if the benefits were known, the fear of crop loss from use of these techniques would still be an impediment to their use.

Because of the farmers' fear of crop loss, crop protection specialists making pest control recommendations may feel the need to carry malpractice or liability insurance, which presently is not available. Such liability considerations probably discourage some individuals from entering this job field.

Perhaps the greatest obstacle, however, is posed by the lack of skilled manpower. A broad-scale integrated pest management industry has not developed because of the recent state of develepoment of integrated pest management techniques and farmer resistance. Until integrated pest management gains wider recognition as a sound approach to pest control, an adequate supply of professional crop protection specialists will likely be lacking.

The availability of specialists is also limited by the number of institutions that offer appropriate training programs, which, in turn, is affected by the demand for integrated pest management. Qualified individuals are not yet available in many areas of the country. Crop protection specialists require a broad understanding of pests, including insects, weeds, nematodes, and fungi; their identification, behavior, and life cycles; their natural control agents and other environmental influences; economic thresholds; crops and modern farming practices; and complete and up-to-date knowledge of control measures. Training programs for these individuals require heavy emphasis on a number of disciplines in the physical, biological, and agricultural sciences as well as extensive field experience. Not many will undergo the rigorous training without some assurance that integrated pest management offers a career opportunity.

In addition, individuals qualified as crop protection specialists will want some recognition of their training and will need protection from criticism of the practices of less-qualified individuals. Such recognition of qualifications is also important to a potential crop protection specialist because it may influence his ability to obtain adequate liability insurance coverage.

As the potential of integrated pest management gains wider recognition, most of the obstacles described above will become less of a hindrance. The fact that pest problems continue to develop with current methods of control will be a greater impetus to look for new approaches. As new practices reach the field and are successful, they will gain wider recognition.

Table 3

Estimated Potential Manpower Requirements for Integrated Pest Management[1] (*61*)

State and region	Total cropland used for crops (1,000 acres)	Field scouts	Professional crop protection specialists
Maine	550	275	19
New Hampshire	152	76	6
Vermont	592	296	20
Massachusetts	212	106	8
Rhode Island	25	13	1
Connecticut	178	89	6
New York	4,417	2,209	148
New Jersey	522	261	19
Pennsylvania	4,421	2,211	148
Delaware	454	227	16
Maryland	1,437	719	48
District of Columbia			
Northeast	12,960	6,480	432
Michigan	5,989	2,995	200
Wisconsin	9,033	4,517	301
Minnesota	17,369	8,685	579
Lake States	32,391	16,196	1,080
Ohio	8,739	4,370	292
Indiana	10,426	5,213	347
Illinois	20,314	10,157	678
Iowa	20,250	10,125	675
Missouri	11,142	5,571	372
Corn Belt	70,871	35,436	2,363
North Dakota	26,633	13,317	888
South Dakota	16,476	8,238	550
Nebraska	19,041	9,521	635
Kansas	26,402	13,201	881
Northern Plains	88,552	44,276	2,952
Virginia	2,649	1,325	89
West Virginia	754	377	26
North Carolina	4,054	2,027	136
Kentucky	3,785	1,893	127
Tennessee	4,101	2,051	137
Appalachian	15,343	7,672	512
South Carolina	2,326	1,163	78
Georgia	4,104	2,052	137
Florida	2,322	1,161	78
Alabama	2,832	1,416	95
Southeast	11,584	5,792	387
Mississippi	4,910	2,455	164
Arkansas	7,023	3,512	234
Louisiana	3,735	1,868	125
Delta	15,668	7,834	[illegible]
Oklahoma	9,537	4,769	318
Texas	23,925	11,963	798
Southern Plains	33,462	16,731	1,116
Montana	14,356	7,178	479
Idaho	4,939	2,470	165
Wyoming	2,196	1,098	74
Colorado	9,218	4,609	308
New Mexico	1,430	715	48
Arizona	1,271	636	43
Utah	1,353	677	46
Nevada	539	270	18
Mountain	35,302	17,651	1,177
Washington	7,196	3,598	240
Oregon	3,964	1,982	133
California	8,608	4,304	287
Pacific	19,768	9,884	659
Continental United States	335,901	167,950	11,200
Alaska	14	7	1
Hawaii	179	90	3
Total United States	336,094	168,047	11,204

[1] Based on one field scout per 2,000 acres and one professional crop protection specialist per 30,000 acres. Total may not add due to rounding.

Fear of crop loss is sometimes overemphasized. Fields under the supervision of an experienced professional pest manager should be less susceptible to crop losses. Once an economic threshold is established and a field is monitored continuously, the specialist will take whatever control measures are necessary to keep the pests below damaging levels. The risk of crop loss is reduced because fluctuations in the level of pests are likely to occur more slowly in areas under maximized natural control than in areas where ecological disruptions, such as those caused by unwise pesticide use, have occurred.

Even constraints such as the state of development of new techniques and the availability of skilled manpower should be less of an obstacle in the future. The concept of maximizing the use of natural control systems and of using pest suppression techniques only when necessary can be applied regardless of the type of suppression technique used. Until economic thresholds are determined, it may be necessary to conduct pest suppression to keep pest population levels at a conservatively low level, but as thresholds are determined and new techniques are further developed, one can expect integrated pest management to become ever more effective and economical. Also, as the career potential of crop protection specialists gains greater recognition, training programs should develop rapidly. The potential need for such specialists is shown in Table 3.

The Federal Government can stimulate the development of integrated pest management by making it a viable career and by developing and testing alternative pest management techniques. The Administration's program to accomplish these ends is described in Chapter V.

summary

For several agricultural crops now receiving heavy pesticide applications, the effectiveness and economic advantages of integrated pest management have been well demonstrated. Obstacles which currently prevent a wider use of this approach include the farmers' lack of incentive to change pest control practices, the complexity of these new management techniques, inadequate information on economic levels, an inadequate supply of trained professionals, and a limited number of fully developed nonchemical control techniques. Because it offers the promise of more dependable pest control with minimum adverse environmental effects, often at lower cost, the obstacles to more widespread adoption of integrated pest management should begin to be overcome.

464-590 O - 72 - 4

chapter iii environmental, genetic, and metabolic approaches to pest control

Although much of the current pest control research is confined to chemical pesticides, a growing recognition of adverse side effects has gradually led to a search for alternative control methods. Some nonchemical techniques have been known for centuries and others are of much more recent discovery. Many methods which seemed promising years ago remain promising but untested.

The previous chapter discussed integrated pest management as a concept with a few examples of field applications. This chapter and the one that follows describe several alternative methods of pest control which may be used singly or in combination as part of an integrated program.

A number of pest control alternatives holding considerable promise have been used to varying degrees. The techniques involve the use of environmental manipulations or cultural methods (such as changes in planting, plowing, irrigation, and other farming practices), genetic changes (in both crop resistance and pest susceptibility), and metabolic approaches (such as the use of sex attractants or hormones which influence insect development). Biological and genetic methods, such as the release of predators and parasites and the use of resistant varieties,

can also be used to supplement these techniques. All of them reduce the need for chemical pesticides.

The development of these alternatives depends upon research and upon knowledge of the pest, including its behavior, metabolism, and the important environmental factors which affect it. Lack of such understanding has hindered progress and the development and evaluation of alternatives.

environmental manipulations

Environmental manipulations (or cultural methods) require changes in standard farming practices to change the pests' environment adversely or to improve that of its natural enemies. These changes in farming practices can occur in land preparation and cultivation, crop rotations (the sequence of crops planted in a field), fallows (idle periods in field use), timing of planting and harvesting, and timing of irrigation. Also, pest-free seed, addition of soil organic matter or nutrients, and the removal of plants which may provide food or shelter for the pest can be used to curb pest concentrations. These practices are important because they strongly influence the habitat, availability of food, reproductive areas, and protective cover of a potential pest or its natural enemies.

Often conditions that optimize crop production also favor increased insect levels. Exclusive production of a single crop (monoculture), for example, can result in the proliferation of insect-damaging species that feed on the crop. Forests which contain only one or a few species of trees provide an excellent opportunity for buildup of insect populations or the spread of diseases such as the Dutch Elm disease. Changes in irrigation and fertilizer use can furnish more favorable habitats for both insects and weeds by providing pools of water for the reproduction of some insects and by providing the nutrient and water needs of weeds.

Just as environmental modifications can create conditions favorable to insect development, environmental conditions often can be modified to affect populations adversely while at the same time remaining favorable for optimum yields. For example, farmers have plowed their fields for centuries for a variety of reasons, including soil aeration and weed control. Plowing, however, can also provide valuable control of insects by physically destroying them during the soil-inhabiting period of their life cycles. Spring plowing can destroy up to 98 percent of the corn earworm pupae that survive the winter. *(70)* Research indicates that even alterations in plant spacing may influence insect populations by changing their microhabitat and the density of their food supply. *(70)*

Changes in planting and harvesting schedules can make the crop less available as a habitat during critical stages of insect development. Planting cotton seed over as short a time period as possible, for example, allows cotton to mature simultaneously throughout the planted area. This limits the number of boll weevil and pink bollworm generations by minimizing the duration in which mature cotton is available for attack. By destroying the stalk after harvest—the winter habitat of the boll weevil—the ability of that pest to survive the winter is reduced.

Diversification of crops lessens the number of any particular insect species by limiting the availability of a single food source. In so doing, diversification may simultaneously provide an alternate food source for either the insect pest or its natural enemies and suitable conditions for the natural enemies to reside or reproduce.

If alternate food sources are available for predators or parasites that prey upon an insect pest, population levels of the natural enemies will be less affected by fluctuations in the pest populations. Normally a pest population can

increase relatively quickly in an adequate habitat with the crop as its food source, while predators and parasites do not become established until the pest population (their food source) is established. If the natural enemies of the pest can be sustained through alternative food supplies, the pest can be held in check more effectively. (*21*)

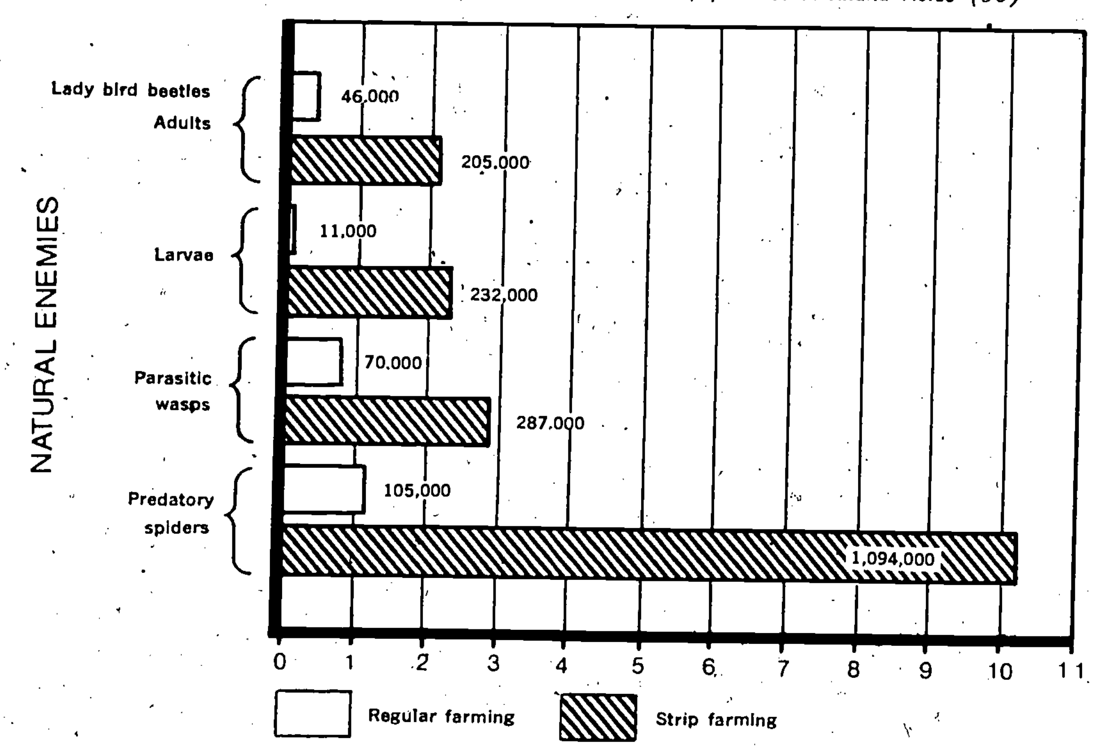
Strip cutting has been used to a limited extent to maintain a suitable environment for natural controls. Strip cutting involves harvesting only a fraction of a crop at one time (usually one-half or one-third) in order to preserve a stable habitat for natural enemies in the unharvested portion of the field. The cut portion is then allowed to produce new growth while another portion is harvested. Planting and harvesting of the field are so timed that maximum yield can still be maintained. (*71*) This method has been successfully demonstrated in California alfalfa fields and is particularly promising for warmer regions of the United States where there is an extended growing season. (See Figure 4.)

In a similar procedure, flies have been controlled in cattle feedlots by continually removing only a fraction of the accumulated manure in order to maintain adequate levels of the fly parasites in the remaining manure. (*30*)

Disease-free seed, combined with crop rotation, has controlled several seedborne diseases of vegetables such as cabbage, turnips, cauliflower, celery, and garden beans. (*5*, *72*)

Figure 4

Average Number of Natural Pest Enemies (Predators and Parasites) per Acre in Alfalfa Fields (*50*)



Crop rotation, the sequence and types of crops planted, can be used to reduce crop damage from nematodes (worm-like, soil-inhabiting pests) and diseases, as well as to improve soil. Although the most effective control of *Verticillium* wilt disease in cotton is through the planting of resistant varieties, planting grasses, sorghum, small grains, and corn in rotation with cotton tends to reduce losses caused by this disease. (*47*)

Although rotations can seldom control more than two or three species of nematodes, they are an important control method for the major nematode problems.

Removal of crop residues—crop sanitation—is a valuable approach in reducing diseases, insects, nematodes, and weeds by removing the food or habitat of the pests. Standard practices involve the complete burial of crop residues, burning of crop residues, and cultivation to destroy those plants which have seeded themselves. Unfortunately, some good crop sanitation practices may cause environmental problems of their own. For example, cultivation practices can leave fields exposed to serious water and wind erosion, and the burning of crop residues adds to air pollution.

Preventing weed growth is the most basic of all weed controls. Complete prevention requires such environmental manipulations as the use of seeds free of any weed seed and proper quarantine and regulation of contaminated crop seeds. Other preventive weed-control techniques involve physical methods, such as tilling (by both hand and machine), mowing, flooding, and smothering with nonliving material.

The most effective agent in cropland weed control, however, is the crop itself. A vigorously growing crop of sufficient density will compete with any annual weeds. In many instances, weed control measures are needed only to protect the crop until it is sufficiently established to compete effectively.

plant breeding and genetic factors

Breeding pest-resistant crops has been one of the most successful pest control techniques for pests other than weeds. There are now 152 varieties of 23 crops resistant to nematodes (*26*), more than 100 plant varieties resistant to a total of 25 insect pests (*39*, *55*), and probably at least 150 varieties resistant to a great diversity of plant diseases (*35*). Ideally, resistance factors for insects, diseases, and nematodes should be incorporated into every crop.

Even partial resistance of a crop variety can greatly reduce the economic damage from an insect and thereby the need for other pest control measures that may disrupt natural control. (*53*) Thus, use of a resistant variety easily fits into the existing ecological pest control system for any crop. Insect pests that are controlled by resistant varieties include the Hessian fly, wheat stem sawfly, spotted alfalfa aphid, and European corn borer.

In 1900, less than 1 percent of the total U.S. acreage in agricultural production used resistant crop varieties developed by man. In 1965, more than three-fourths of the total acreage in production was planted with varieties which did not exist prior to 1900. Most of these varieties incorporate varying degrees of resistance to one or more important diseases, insects, and nematodes. Without the development of varieties resistant to certain destructive pathogens and aimed at high yield and quality, commercial production of some crops would literally have ceased in many areas of this country. For certain grains, 95 to 98 percent of the total acreage is planted with resistant varieties that have been developed in the last 20 years. (*41*)

In general, plant resistance to insects appears to be reasonably durable. In the case of wheat that is resistant to the Hessian fly, control in some varieties still exists after 30 years. However, new biotypes of Hessian flies that can attack resistant wheat varieties continue to

464-590 O - 72 - 3

appear. Also, there is some evidence that the spotted alfalfa aphid may have overcome the variety of alfalfa bred to resist it. (*45*) Nevertheless, even in alfalfa, genetically resistant strains continue to be an important form of pest control.

Developing resistant plants is a slow process. Ten years or more are usually required to develop a variety with resistance to a single pest and perhaps twice as long for two or more pests. Multiple resistance is needed in crops, however, and progress is being made toward this goal. For example, barley varieties with resistance to five diseases and tobacco resistant to six diseases are now available in certain areas.

Despite the lengthy development time and the costs of developing resistant strains, the economic rewards are great. The total cost of research conducted by Federal and State agencies and private companies to develop resistant varieties for the Hessian fly, wheat stem sawfly, European corn borer, and spotted alfalfa aphid was about $9.3 million. But the annual savings in reduced losses to the farmer is estimated at $308 million. The net monetary value of the research is about $3 billion over a 10-year period, or a return for each research dollar invested of approximately $300 in reduced crop losses. (*65*)

New concepts in breeding for pest resistance place heavy emphasis on genetic diversity in the control of plant pests. (*11, 34, 59*) By mixing resistant and susceptible varieties, there is less chance of developing strains of pests which have adjusted to their environment in a manner similar to the development of insect resistance to specific pesticides. The disastrous outbreak of southern corn blight in 1970 has emphasized the fallacy of relying on a single genetic system.

Future work with genetics may be extended beyond plants to include insect pests. This would involve the search for traits that increase an insect's susceptibility to pest control measures. By rearing in captivity strains carrying this susceptibility, planned releases would be able to spread the trait throughout the population. (*70*) Although some research has been performed on this technique, it has not yet been field tested.

metabolic alterations

Insects rely heavily on smell to find mates and food. Many female moths emit a selective scent—a sex pheromone or sex attractant—to lure males of their species. (*8*) Boll weevil males also produce a sex pheromone which attracts both sexes, but after hibernation they cannot produce the scent until they feed on a cotton plant. Many ants lay trails to guide others to a food source. Bumble bees and stingless bees also use scents to designate paths to food sources. A parasitic wasp locates corn earworm eggs by their odor. Many blood-sucking pests locate animals by detecting the carbon dioxide and other odors of their breath.

Each pheromone is reasonably specific in its effects and is effective in extremely minute quantities. When its chemical structure is identified, a pheromone can be synthesized for use as an attractant in the field to lure the pests to a trap, and a sex pheromone can be used more broadly to confuse the males who are then unable to locate the females.

In an effort to control the gypsy moth, 300,000 strips of paper containing a sex pheromone were dropped on each of several infested 40-acre regions in the Northeast. The odor permeated the air, overpowering natural female pheromones. The male guidance systems were disturbed in much the same way that radar is jammed in military operations, so that the males could not find females with which to mate. (*4*)

The effectiveness of sex attractants for pest control is still in the testing stage. Their use seems most promising in areas of light infestations.

Traps coated on the inside with a sticky flypaper-like substance impregnated with an attractant to lure males inside have long been used for detection of the gypsy moth in the Northeastern States. In 1971, traps were baited with synthetic pheromones. Economics proved encouraging because each trap used 20,000 times as much of the synthetic attractant as the live female produced, but the total cost of the chemicals for 70,000 traps was only about 50 cents. (*4*)

A second important class of physiological compounds is hormones, which regulate the growth, development, and reproduction of insects and other invertebrates. Enough is known about insect hormones to undertake the development of selective hormonal insecticides, which selectively disrupt the insects' physiological processes. Because these processes do not occur in higher animals, there is a good possibility that hormonal insecticides in reasonable doses would not affect wildlife, fish, domestic animals, or man. (*49*)

Juvenile hormones (JH) currently offer the greatest immediate potential for commercial development. These hormones, occurring naturally in low concentrations at various points in the life cycle of an insect, can disrupt a wide range of body functions when applied in greater quantities or at a different time in the life cycle of an insect. For example, they can adversely affect development and reproduction, terminate diapause (a hibernation-like stage in insect development), and prevent eggs from hatching.

Success in mosquito control has been reported with synthesized insect hormones in California. A 99 percent reduction in the level of the species *Aedes nigromaculis*, known to be totally resistant to conventional pesticides, was obtained in trial applications of a JH. (*3*)

Control through the use of synthetic insect JH analogs is progressing with significant industrial interest. (*3*) Large-scale field testing was initiated in Central America during the winter of 1971, with future trials on more than 2 dozen insects and 20 different crops scheduled in 1972. (*74*)

Further development of JH is hindered by problems of synthesis, high production costs, the lack of toxicity data, and insufficient information on the effects on nontarget insects. Some JH and related compounds are simple molecules, however, so their industrial production should be economically feasible.

summary

Cultural methods and genetic resistance are two approaches to pest control which are in widespread use in agriculture. Because they are basically preventive measures, their importance can easily be underestimated. Metabolic alterations, by contrast, are designed for use in areas with existing pest populations. While in an early stage of development, metabolic techniques appear to have great potential for pest control in the future.

chapter iv biological and other control methods

In addition to the methods described in Chapter III, several other techniques of pest suppression are in various stages of development. These range from such traditional biological controls as the release of predators and parasites, to long-recognized but barely developed methods such as the use of pest-specific diseases, and to more recent techniques such as pest sterilization or the use of electromagnetic radiation.

predators and parasites

The use of predators and parasites—natural pest enemies—is almost synonomous with "biological pest control" today. All plant and animal species are subject to natural forces that control their population levels. Natural enemies, along with other environmental influences, maintain a natural balance among populations of plant and animals in an ecosystem.

There is little question that the parasites, predators, and diseases (discussed in a later section) existing in a field are the greatest resource that we have for effective pest suppression and management. Without natural controls, satisfactory insect pest control by any single or combination of means would become virtually impossible. Although this view cannot be documented in a strict sense, it can be shown by the many examples of serious insect pest

problems emerging when beneficial insects were killed by broad-spectrum insecticides.

The deliberate use of natural predators and parasites depends on the nature of the pest. If the pest is native to this country, treatment usually consists mainly of creating an environment favorable to the survival of the predator or parasite and if necessary, increasing its numbers by timed periodic releases of mass-reared insects. (See Table 4.)

Table 4 (*61*)

Examples of Parasites and Predators of Potential Value in Pest Suppression Through Inundative Releases.

Biological control agent	Pest
Nematodes:	
DD-136 (Biotrol NCS)	Codling moth; European corn borer.
Heterotylenchus autumnalis	Faceflies.
Reesimermis nielseni	Mosquitoes.
Parasitic insects:	
Apanteles species	Various caterpillars.
Bracon kirkpatrick	Pink bollworm.
Cuban fly	Sugarcane borer.
Lysiphlebus testaceipes	Aphids.
Macrocentrus ancylivorus	Oriental fruit moth.
Macroterys flavis	Brown soft scale.
Micropletis	Bollworm complex.
Pediobius foviolatus	Mexican bean beetle.
Several tachinid flies	Bollworm complex.
Trichogramma	Various moths and butterflies.
Phytophagous insects:	
Agasicles (beetle)	Alligatorweed.
Bactra veratana (moth)	Nutsedge.
Predacious insects:	
Coccinella (lady bugs)	Aphids.
Cryptolaemus montrouzieri	Mealy bugs and soft scale.
Hippodamia (lady bugs)	Aphids; bollworm complex.
Other:	
Cyprinidon variagatas (saltwater fish)	Mosquitoes.
Dung beetles	Hornflies.
Gambusia (freshwater fish)	Mosquitoes.
Marisa (snail)	Aquatic weeds.
Mollienesia latipinna (saltwater fish)	Mosquitoes.
White amur	Aquatic weeds.

Many of our major pests are of foreign origin. (*19*) When a pest has been introduced from another country, the chance of control by native enemies is slight. It is therefore necessary to search for natural enemies of the pest in its original habitat. The search for predators and parasites is often long and laborious, and the potential adverse impacts of their importation must be taken into account.

The use of parasites and predators has some distinct advantages over other methods of pest suppression. Once populations of a natural enemy are completely established, control of the pest is relatively long lasting in perennial crops. For annual crops whose postharvest remains are destroyed yearly, control depends on continued introduction of natural enemies. The long-term benefits of biological control make the method relatively inexpensive. (*70*)

In 1944, two species of leaf-feeding beetles were introduced to suppress Klamath weed, a weed of foreign origin which spread over 4.6 million acres in California and adjacent States. (See Figure 5.) In a relatively few years, these predatory beetles were successful in checking further spread of the weed. Unaided by supplementary means, they reduced Klamath weed to the extent that it was no longer of economic significance in California. (*2*) The investment for control was only \$200,000 to \$300,000. Considering the number of years since control was successful, the savings from not applying herbicides, and the increase in land values as a result of killing the weed, the benefits from the program may now be conservatively calculated at several million dollars.

The effectiveness of several snails and fish (for example, the marisa snails and the white amur fish) for control of certain aquatic weeds has been demonstrated in exploratory studies. Work needs to be intensified to exploit the full potentialities of these biological agents to control the weeds that infest ponds, reservoirs, lakes, streams, canals, and other waterways.

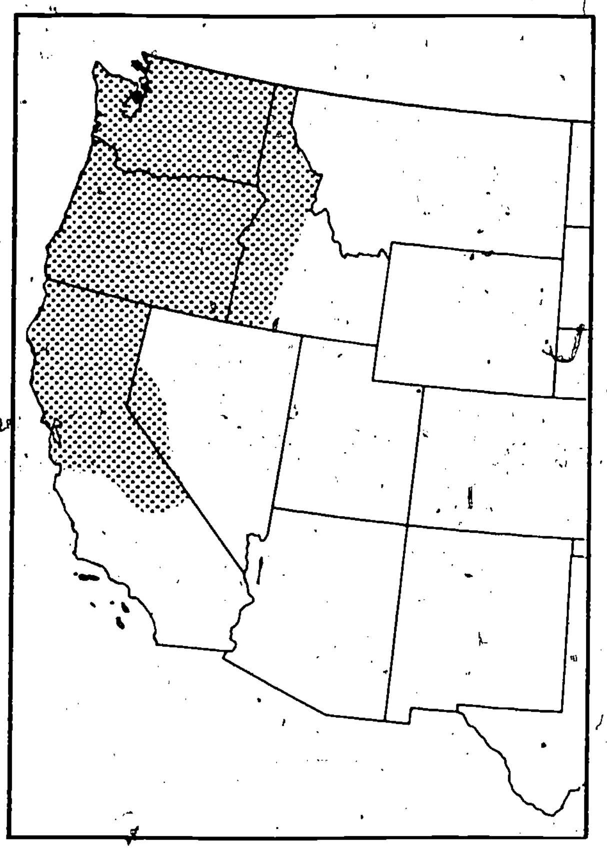
Trichogramma, a tiny wasp that is an egg parasite of most butterfly and moth pests, has been used successfully to control the cotton bollworm. Often the parasite is used like a chemi-

cal insecticide. When pest populations threaten to get out of hand, huge numbers of the wasps, which have been reared in insectaries, are released to destroy the pest. If permanent control is not obtained, they can again be released to suppress further infestations. This causes little disruption of the ecosystem and is economically competitive with chemicals. (*48*)

It has been clearly demonstrated that certain soil organisms may be suppressed or destroyed by the action of other soil-inhabiting saprophytes (plants which live off dead or decaying organic matter) or predators. However, in contrast to developments in biological control of insects, direct use of parasites or antagonists for controlling plant pathogenic fungi or bacteria has not been explored intensively and results of experiments have not been consistent.

Figure 5

Range of Klamath in the Western United States Prior to Introduction of Predatory Beetles (*63*)



Biological control of nematodes holds some promise, but it cannot be fully exploited until the microbiological ecology of the soil is understood and becomes subject to management. (*17*) Many types of microscopic plants and animals are parasitic, predacious, or pathogenic to plant nematodes. These organisms already exert considerable influence in limiting nematode populations and reducing crop losses. (*17*, *40*)

The effectiveness of natural enemies of nematodes is usually regulated by the organic substrate in soil. Natural enemies of nematodes are generally increased or maintained by the organic matter in soil, whose chemical decomposition products are toxic to nematodes. To fully exploit their potential for biological control, the life histories and population dynamics of these organisms must be manipulated and regulated through management of the soil environment.

The techniques involved in carrying out a pest control program based on the release of natural enemies are sophisticated and complex. Owing to limited investigation of new agents and the lack of the necessary insect-rearing facilities, only a small fraction of the total number of natural enemies of the more important pests has been identified.

When a natural enemy of a pest is located and introduced, there is no guarantee that it will be effective. It may be unable to adapt completely to its new surroundings, and even when fully established, the predator or parasite may be only a minor influence on the population dynamics of the pest.

The introduction of insect parasites and predators poses potential hazards to ecosystems. The possibility of such organisms attacking native insects that may be beneficial, or at least

not harmful, exists. An elaborate screening procedure, therefore, must be employed to prevent such threats.

Likewise, in importing biocontrol agents such as insect enemies of noxious weeds, extreme care must be taken to ensure that they will not become pests of beneficial plants. Insects that attack a weed-host might conceivably attack a botanically related beneficial plant. In view of this, intensive investigations are undertaken prior to introductions and releases. If there is any evidence of the insect's capability to survive on a useful plant, the species are not imported.

Boundaries are another problem inherent in any biological control program. When a predator is released, it is virtually impossible to confine it to the place where it is released. Predators and parasites placed in one field are just as likely to occupy neighboring fields as the one in which they are released, so that the benefits of a particular release are often hard to define. For this reason biological control is better suited to a regional rather than to a farm-by-farm pest control effort.

The difficulties created by the mobility of predators are twofold. First, pest control for a species in one locale may affect that species in areas where it is considered beneficial. For example, the use of a small beetle, *Agasicles*, to control the alligator weed in the South has both proponents and antagonists. Considered a serious water pest by many, this plant was judged by others as an important food source for wildlife. Other examples include the cacti, considered by some as weeds and by others as ornamentals and an emergency source of food for cattle under drought conditions, and the salt cedar, a weed pest that is an important habitat for doves.

Second, populations of natural enemies released in one field may be adversely affected by pesticides used in a neighboring field. Thus, due to differences in neighboring conditions, the overall effectiveness of a biological control attempt can be drastically reduced.

Importations of predators and parasites have resulted in complete control of 42 pests, substantial control of 48 pests, and partial control of 30. (*19*) Some examples of biological control in the United States are contained in Table 5. Although these are but a fraction of our important pests, few other methods have resulted in such long-term control.

microbial agents

Another very promising control technique is the use of pathogenic (disease-causing) microorganisms such as bacteria, viruses, protozoa, fungi, and their byproducts to control a given pest species. (*15, 31*) Their potential has been recognized since the turn of the century, when, for example, the nuclear polyhedrosis virus of the gypsy moth was considered although not fully developed for control of the gypsy moth. (*25*)

Some time before 1930, the European spruce sawfly was introduced into Eastern Canada. During the following decade, it proliferated in the absence of a specific virus which had kept it in check in Europe. Spreading through New Brunswick, through Newfoundland, and down into the Northeastern United States, the sawfly killed several thousand square miles of standing timber. Some time in the middle 1930's the virus disease was introduced from Europe into Canada apparently by accident, and in 1937 and 1938 it was known to have killed larvae from Quebec to Vermont and New Hampshire. By 1940, this tremendously harmful population of insects was virtually decimated, and damage essentially ceased. The virus disease was later introduced into Newfoundland with the same beneficial results. (*7*)

Similarly, the European pine sawfly is largely controlled in Europe by a nuclear polyhedrosis virus, but the insect was introduced many years ago into the North American continent without

Table 5

Examples of Biological Control in the United States (19)

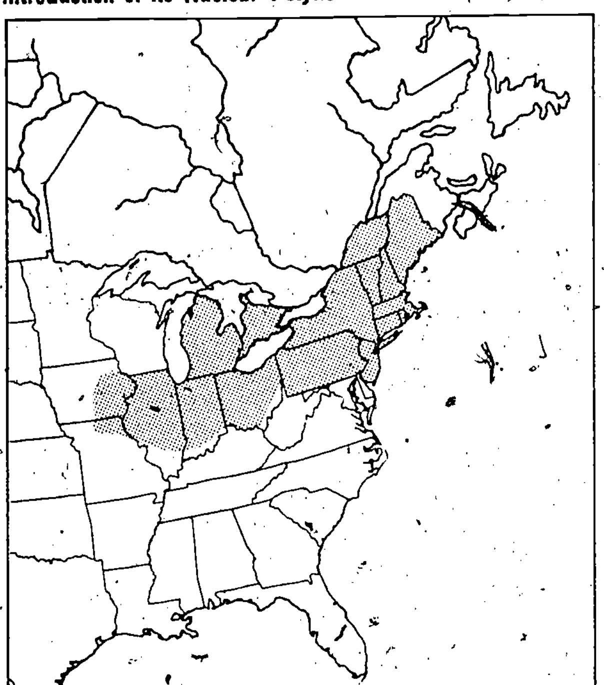
Pest	Crop attacked	Type of natural enemy	Degree of control
Alfalfa weevil	Alfalfa in California	Parasite (*Bathyplectes*)	Substantial
Alfalfa weevil	Alfalfa in Mid-Atlantic States	Parasites	Complete
Avocado mealybug	Guava, avocado, fig, mulberry in Hawaii	Parasite (*Pseudaphytis*)	Substantial
Black scale	Citrus in California	Parasite (*Metaphycus*)	Substantial
Brown-tail moth	Deciduous forest and shade trees in Northeastern United States	Parasites	Complete
California redscale	Citrus in California	Parasites	Substantial
Cereal leaf beetle	Grain in Michigan	Parasites	Substantial
Chinese grasshopper	Sugarcane in Hawaii	Parasite (*Scelio*)	Substantial
Citrophilus mealybug	Citrus in California	Parasites	Complete
Clover leaf weevil	Eastern United States	Parasites	Completed
Coconut scale	Coconut and other palms in Hawaii	Predator (*Telsimia*)	Substantial
Comstock mealybug	Apple in Eastern United States	Parasites	Complete
Cottony cushion scale	Citrus in California	Predator (*Vedalia* beetle)	Complete
European larch sawfly	Northeastern United States	Parasites	Substantial
European pine sawfly	Eastern United States	Parasites	Complete
European pineshoot moth	Northeastern United States	Parasites	Substantial
European spruce sawfly	Northern United States	Parasites	Substantial
European wheat stem sawfly	Eastern United States	Parasites	Complete
Florida redscale	Citrus in Florida	*Aphytis holoxanthus* from Israel	Substantial
Greenhouse whitefly	Vegetables and ornamentals in New York	Parasite (*Encarsia*) from Israel	Substantial
Japanese beetle	Turf in Eastern United States	Disease and parasites	Substantial
Larch casebearer	Northeastern United States	Parasites	Substantial
Linden aphid	Linden trees in California	Parasites	Complete
New Guinea sugarcane weevil	Sugarcane in Hawaii	Parasite (*Ceromasia*)	Substantial
Nigra scale	Ornamentals in California	Parasite (*Metaphycus*)	Substantial
Olive scale	Olive, deciduous fruit trees, ornamentals in California	Parasite (*Aphytis*)	Substantial
Oriental beetle	Sugarcane in Hawaii	Parasites	Substantial
Oriental moth	Shade trees in Massachusetts	Parasite (*Chaetexorista*)	Substantial
Pea aphid	Alfalfa in North America	Parasite (*Aphidius*)	Substantial
Pink sugarcane mealybug	Sugarcane in Hawaii	Parasite (*Anagyrus*)	Substantial
Purple scale	Citrus in Texas and Florida	Parasite (*Aphytis*)	Complete
Rhodes grass scale	Grass in Florida	Parasite	Complete
Rhodes grass scale	Grass in Texas	Parasite	Substantial
Satin moth	New England, Pacific Northwest	Parasite	Substantial
Spotted alfalfa aphid	Alfalfa in Southwestern United States	Parasites and resistant varieties	Substantial
Sugarcane aphid	Sugarcane in Hawaii	Parasite, various predators	Substantial
Sugarcane leafhopper	Sugarcane in Hawaii	Predator (*Cyrtorhinus*)	Complete
Taro leafhopper	Taro in Hawaii	Predator (*Cytorhinus*)	Substantial
Torpedo bug plant hopper	Coffee, mango, citrus, etc., in Hawaii	Parasite (*Aphanomerus*)	Substantial
Walnut aphid	English walnut in California	Parasites	Complete
Western grape leaf skeletonizer	Grapevine in United States	Parasites	Substantial
White peach scale	Mulberry, papaya, etc., in Puerto Rico	Predator (*Chilocorus*)	Substantial
Yellow scale	Citrus in California	Parasite	Substantial
Weed			
Alligator weed	Southeastern United States	*Agasicles* beetles	Substantial
Klamath weed	Pacific States	*Chrysolina* beetles	Complete
Lantana rangeweed	Hawaii	Several moths and beetles	Substantial
Prickly pear	Santa Cruz Island, California	Cochineal scale and coreid bugs	Substantial
Puncturevine	California and Hawaii	*Microlarinus* beetles	Substantial some areas
Tansy ragwort	Pacific States	Cinnabar moth	Partial to complete

this specific disease. In 1949, the insect caused severe damage in pine plantations and tree nurseries in Southern Ontario, in Quebec, and in the Northeastern United States. (See Figure 6.) A few diseased specimens were sent from Sweden to Canada for propagation. In field experiments the virus controlled the insects in both Canada and the United States. (*9*, *22*) Indeed, in this case also, its spreading in the population provided substantial natural control.

Although only two bacterial pathogens have been registered for use in the United States, numerous additional bacterial and viral pathogens are under development for pest control. (See Table 6.) The viruses occur naturally in the environment, and their epidemics often decimate high pest populations. Their advantage in pest control is that they are highly specific; most are able to infect only one insect species.

Figure 6

Range of European Pine Sawfly Prior to Introduction of its Nuclear Polyhedrosis Virus *(18)*



Concern has been expressed that these pathogens may mutate to attack desirable species. However, insect pathologists believe that the likelihood of such changes is very remote. Because these pathogens occur in astronomical numbers in nature, it is unlikely that industrial production would significantly increase the chances of such mutation. For example, nuclear polyhedrosis viruses currently under development are unique. They are rod-shaped, contain double-stranded DNA, and have a special protein coating. They have no known counterpart in other animal or plant viruses.

The two federally registered pathogens, both bacterial agents, *Bacillus popilliae* (milky spore disease) and *Bacillus thuringiensis*, have been shown to be quite effective in the control of Japanese beetles and numerous caterpillar pests, respectively. Research is currently in progress on the latter to demonstrate its ability to control the gypsy moth, a serious hardwood forest pest in the Northeastern United States. More than 1 million pounds of this pathogen is sold annually in the United States for the control of caterpillars on vegetables and cotton.

In addition to the two registered bacterial agents, temporary permits have been issued by the Environmental Protection Agency for pilot testing of the *Heliothis* polyhedrosis virus to control the bollworm (a serious pest of corn, cotton, tobacco, and tomatoes). Field experiments are well underway with the specific viruses of the cabbage looper (a major pest of cole crops), the gypsy moth, the Douglas fir tussock moth, and the pine sawfly. Use of these micro-organisms in insect control awaits proof of safety and reliability and better mass production methods. The promise of effective and environmentally sound pest control with these agents makes this research of paramount importance.

Table 6

Examples of Pathogens under Development by Government and/or Industry for Use Against Agricultural and Forest Pests[1] (61)

Pathogens under commercial production	Important agricultural pests controlled
Bacillus popilliae (Trade name—*Doom*)	Japanese beetle
Bacillus thuringiensis (Trade names—Biotrol ® BTB, Thuricide ®, Dipel, Parasporin ®, Bakthane ®, L69, Agritrol ®)	Lepidopterous pests (larvae of moths and butterflies)
Nuclear polyhedrosis virus (temporary label) (Trade names—Biotrol VHZ, Viron/H ®)	Cotton bollworm (corn earworm)
Pathogens under serious development	**Important agricultural pests involved**
Viruses (Product names—Polyvirocide, Biotrol VPO, Biotrol VSE, Biotrol VTN)	Cabbage looper, Diamond back moth, Beet armyworm, Tobacco budworm, Pink bollworm, Cotton leaf perforator, Alfalfa looper, Fall armyworm, Saltmarsh caterpillar, Douglas fir tussock moth, Gypsy moth, Codling moth, Red banded leaf roller, European pine sawfly, Pine sawfly, Spruce budworm, Soybean looper, Citrus red mite, Mosquitoes
Fungus—*Hirsutella thompsonii*	Citrus rust mite
Metarrhizium anisopliae	Pecan weevil, cornborer, leafhoppers, sugarbeet curculio, cutworm frog-hopper, rhinoceros beetle, wheat cockchafer
Beauveria bassiana (Product name—Biotrol FBB)	Corn rootworm, white fringed beetle, Colorado potato beetle
Protozoan—*Nosema locustae*	Major range grasshopper species in Montana
Pathogens known, but not yet under serious development	**Important agricultural pests involved**
Nuclear polyhedrosis viruses	Yellow striped army worm, Almond moth, Indian meal moth, Cotton leaf worm, Alfalfa looper
	Important forest pests controlled
Nuclear polyhedrosis viruses	Great Basin tent caterpillar, Western tent caterpillar, Eastern tent caterpillar, Hemlock looper (Western and Eastern)

[1] Mention of proprietary names does not constitute endorsement by the Council.

There are few examples of plant pathogens intentionally used to control weeds in agriculture, despite the fact that plants are quite susceptible to diseases. The devastation caused by Dutch Elm disease, chestnut blight, and other plant pathogens of desirable plants, however, is an indication of the potential effectiveness that a selected pathogen of a weed may have. Intensive research is needed for discovery, evaluation, and provision of necessary safeguards before pathogens of weeds can be released. Also needed are investigations to gain an understanding of the life cycles and behavior of pathogens in order to develop means of multiplying, dispersing, and causing them to attack harmful weed species.

sterilization

Sterilization of insects was conceived as a possible control method about 30 years ago. (*70*) If a significant number of pests in a population can be sterilized, the obvious result will be a decline in numbers.

Since 1937 it has been recognized that certain chemicals can be used for direct sterilization of insects in the field. The chemicals, developed by the Agricultural Research Service of the Department of Agriculture, have not been employed because they are highly reactive compounds with the potential for causing adverse environmental effects.

Field applications of the sterilization technique have usually involved the mass rearing of an insect pest, its sterilization by irradiation, and its release in the area of infestation. The irradiation causes the reproductive cells of the exposed (usually male) insect to be damaged so that eggs fertilized by it cannot develop. Thus, if each of the sterile males mates several times with fertile females, a sufficient sterile release can decimate the population. This method is totally specific to a single pest species, and with sufficient continued releases, eradication of a species from an area may be possible.

Eradication of the screwworm from Curaçao, a Caribbean island, was accomplished in 1955 by sterile releases. (*38*) The technique was later used in a successful effort to eliminate this cattle pest from the Southeastern United States and to control it in the Southwest. Conducted over a 17-month period, the program used over 3.25 billion flies on 85,000 square miles of the Southeast. (*36*) Sterile male screwworms continue to be released along the U.S.-Mexican border and in areas of outbreaks in an effort to prevent serious reinfestation. Beginning in 1973, it is expected that eradication of the screwworm will be attempted throughout Mexico.

Although early success with the screwworm was encouraging, many outbreaks have occurred in the Southwest during 1972. These outbreaks have resulted from a combination of factors including unfavorable weather conditions and relaxed preventive measures (e.g., reduced surveillance and year-round breeding instead of scheduling births to occur in the winter months when calves are least susceptible to attack). This case illustrates the need for continuing surveillance, preventive measures, and knowledge of the relevant factors in any successful pest control program.

More recent attempts to eradicate 13 other insect species by the sterile male technique have also had some difficulties. (*28*) Most of these cases represented areas densely populated with pests, and the sterile males released comprised too small a fraction of the population to result in significant pest control. The field tests did show the capability of the sterile male technique to reduce insect population levels drastically in areas with already low pest densities. The technique can also work well in conjunction with other methods to reduce pest population levels.

As in the case of biological controls, there is insufficient knowledge of how to mass-rear certain insects, and even when knowledge is available, there is a lack of facilities to do so.

other methods

There is a wide range of ideas for new pest control techniques. Antifeedant chemicals offer a unique approach in that insect pests are inhibited from eating a crop. By chemically making the crop repugnant to the insect, it must look elsewhere for food.

Chemical repellents drive insects away from the area to be protected. The earliest repellent known is smoke. Oils and plant extracts later came into use. Synthetic chemical repellents were developed after 1935, but these generally were for nuisance insects, such as mosquitoes, rather than for plant pests. (*44*)

Electromagnetic energy can also be used as a nonchemical control method. The range of energies includes radio frequency, infrared, ultraviolet, x-ray, and gamma ray. The effects vary from disorientation of the pests and other behavioral effects, to sterilization, and to lethal effects. With the exception of sterilization, few, if any, major field successes can be cited, largely because current costs and lack of technology have thus far confined most experience to the laboratory. Research continues in these new areas in the hope that they will result in important new means of control.

summary

Several promising techniques of pest supression are now in various stages of development. None alone offers the hope of adequate pest control, and with most of them there are obstacles that must be overcome prior to widespread use. Of the techniques described in this chapter, biological controls and pest sterilization have been used in major pest control efforts but are still available only for a small fraction of the important pests. Pathogens have been employed only to a limited extent but appear to hold great promise for the future. Other techniques in early stages of development are likely to play an important role in future programs of pest control.

chapter v
the federal role

Integrated pest management can provide optimal strategies for controlling major agricultural and forest pests. It should bring into practice a wide array of techniques with minimal environmental impact and at lower cost than current practices. The challenge is to overcome the many obstacles which interfere with the large-scale implementation of this approach. The Federal Government can help to meet this challenge.

development of new techniques

As described in Chapters III and IV, there are many new techniques of pest control in various stages of development which have potential as important tools in a pest management program. These and other techniques need to be developed so that crop protection specialists will have more flexibility in determining the best control methods for varying conditions.

Currently, the Federal Government is heavily committed to pest control research. Although in the past much of this effort was related to development of new chemical pesticides and improved application techniques, a large fraction today is devoted to basic research on pests and to the development of nonchemical controls. In fiscal year 1971, the Department of Agriculture (USDA), charged with primary responsibility for pest control, budgeted $75,194,000 for pest control research. The major allotments were $22,131,000 for basic studies, $29,994,000 for nonchemical control methods, $14,874,000 for safer and more effective use of

pesticides, and $5,967,000 for identification of the effects and fate of pesticides. (*65*)

To emphasize the need for better pest control, the President announced comprehensive, new integrated pest management initiatives in his February 8, 1972, Environmental Message to the Congress. These initiatives included added funds for research and development, demonstrations of new techniques, and the stimulation of manpower training programs.

A major research thrust has been initiated to develop new techniques for integrated pest management. The new $3.5 million per year program of the National Science Foundation (NSF), the Environmental Protection Agency (EPA), and the USDA will be conducted with many of our leading universities. It will focus on carrying laboratory research through to field applications on six major crop systems: cotton, alfalfa, soybeans, pine, pome and stone fruits, and citrus.

Much work will be done in this program to determine the economic threshold levels of all the significant pests of these crops. Research will also attempt to develop new cultural methods as well as biological agents to control the most serious pests. The unifying theme of the research will be to develop an understanding of the ecology of these agricultural ecosystems and to apply this understanding to development of more effective integrated pest management methods for these and other crops. It is anticipated that significant new control measures will be developed within 3 to 5 years.

Many promising new pest control and detection techniques await field testing prior to wider-scale use. The USDA initiated an $800,000 field testing program in fiscal year 1972 and is expanding it to a $2.8 million annual effort beginning in fiscal year 1973. This program will involve field testing several of the more promising detection and control techniques. Although each technique requires approximately 3 years of testing before results are final, the level of funding will allow many tests to be run simultaneously.

Among the techniques which appear suitable for field feasibility testing are the tiny parasitic wasp, *Trichogramma*, for tobacco budworm and sugarcane borer; a wasp-like parasite of the green bug on sorghum; *Bacillus thuringiensis* for cotton bollworm, cabbage looper, and gypsy moth suppression; sex attractants for the boll weevil (cotton) and for the codling moth and red-banded leafroller (apples); the sterile male technique for the boll weevil, pink bollworm, codling moth, tobacco horn worm, tobacco budworm, corn earworm, and hornfly of cattle and for Caribbean, Mediterranean, and oriental fruit flies (*37*); and several approaches to weed control (*70*).

demonstrations

The State Extension Services are responsible for providing instruction and information on modern agricultural technology. The Extension Service, in cooperation with the Animal and Plant Health Inspection Service of USDA, State Agricultural Experiment Stations, and State Departments of Agriculture, has conducted a pilot cotton field scout program. To further the acceptance of field surveillance in insect control, cooperative Federal-State pilot scout programs were initiated in 1971 with a project on cotton in Arizona and tobacco in North and South Carolina, two crops which receive heavy pesticide doses. The program was expanded in 1972 to include projects on cotton in all the major cotton-producing States and on apples, potatoes, alfalfa, sweet corn, and some vegetable crops. It is expected that additional crops and areas will be included in 1973. Although to date projects have been concerned basically with the pest complex of a single crop

and almost entirely with insect pests, ultimately these programs will involve pest management of the entire agricultural operation in an area.

Participating farmers will share in paying the scouts' salaries for the first 3 years, after which users are expected to bear the entire costs. This program is intended to generate immediate employment opportunities for current and future trainees as private crop protection specialists.

In contrast to private sector pest control, which is predominantly agricultural and structural (control in and around buildings), Federal programs are directed more toward forest and public health protection, weed control in navigable waters and irrigation ditches, and quarantine and inspection programs. Despite the different emphases and the diversity of its programs, the Federal Government will take the initiative in demonstrating the desirability of integrated pest management in its own pest control programs.

To accomplish this, the President called for a review of all Federal pest control programs to determine which ones could incorporate or demonstrate the concept of integrated past management and new pest control techniques. This review will be conducted by the Federal Working Group on Pest Management, an interagency committee created in 1961. The Working Group reviews the technical aspects of all major Federal pest control programs, of which there were over 3,800 in 1971.

skilled manpower

The future of integrated pest management will be determined in large part by the supply of adequately trained manpower. To provide the many professionals and subprofessionals needed to make recommendations and carry out ecological field surveillance, the President has directed USDA and the Department of Health, Education, and Welfare (HEW) to work together to assist in developing suitable curricula and training programs at appropriate academic institutions throughout the country. Besides providing trainees with field experience, programs will also provide for retraining individuals from other disciplines. One can anticipate a significant demand in agriculture, industry, and various levels of government for individuals trained in pest management. With approximately 350 million acres in agricultural crop production in the United States, excluding pasturelands, there is a potential demand for several thousand professionals and many thousands of field scouts.

Over the past few years, NSF has supported the training of a number of graduate students in the field of integrated pest management. These students will help to provide the teachers necessary to train future crop protection specialists.

The USDA will work with States to develop certification programs for private crop protection specialists. Certification will help assure farmers of the experience and ability of those certified individuals employing modern crop protection techniques. It will also allow the identification of crop protection specialists so that they may continue to be informed of new developments in pest control.

pesticides

Chemical pesticides will be used even with the full implementation of integrated pest management. Thus, the Federal Government must continue research and other efforts to prevent problems resulting from human and environmental exposures to pesticides. Federal effort has included considerable research on the effects of pesticides upon man, animals, and the environment. The health effects of pesticides will be

one of the subjects of study at the new National Center for Toxicological Research at Pine Bluff, Ark., established jointly by the Food and Drug Administration and EPA.

Pesticides have been regulated by the Federal Government since 1910. (*24*) The current law, the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), as amended in 1959 and 1964, (23) requires that chemical pesticides be registered with EPA prior to their sale or movement in interstate commerce and that they must bear warning statements and instructions on the label to prevent injury to people, animals, and plants.

Because FIFRA provides inadequate authority to prevent some of the harmful environmental effects described in Chapter I, the President proposed a new Federal Environmental Pesticide Control Act in his 1971 Environmental Message to the Congress. Among the important provisions of the Administration's bill are: authority to control the use of all pesticides through "restricted" and "permit only" categories of use which require the supervision of certified individuals; streamlining of procedures for cancellation and suspension of pesticides; registration and inspection of establishments manufacturing or processing pesticides; and authority for the Administrator of EPA to regulate the disposal or storage of pesticides and pesticide containers.

A bill containing many of the provisions of the Administration proposal was passed by the House of Representatives in 1971. The Senate passed a similar bill in September 1972. The bills are now in conference.

While EPA currently regulates pesticides, the USDA conducts a number of pest control programs. Agriculture's plant protection and quarantine programs prevent entry into the United States of plant pests from foreign sources, control the interstate movement of such pests as the gypsy moth and the fire ant, and control insect pests such as grasshoppers that build up periodically to the level of large-scale outbreaks. The agricultural quarantine program employs inspectors at ports of entry to intercept dangerous pests. The inspectors also certify commodities and passenger baggage as pest-free through inspection or treatment. Plant protection programs strive to eliminate or contain pests introduced in local areas, to prevent new pest problems in uninfested areas, and thus to reduce the need for widespread control measures.

Because less persistent but generally more toxic pesticides are being used in greater quantities, the threat of acute poisonings from pesticides has correspondingly increased. The Occupational Safety and Health Act of 1970 (*43*) encompasses measures to protect both industrial and agricultural workers. The Act requires that employees maintain records of worker exposure to hazardous chemicals, including pesticides. In addition, it empowers the National Institute of Occupational Safety and Health of HEW to develop the basis for standards and regulations which are promulgated and enforced by the Department of Labor to protect workers from adverse effects of hazardous chemicals.

HEW and Labor are currently developing further standards and regulations under the Act to prevent hazardous exposures of farmworkers to pesticides from contaminated surfaces. The standards are expected to set time intervals for workers to reenter a field after it has been treated with pesticides.

summary

The Federal Government has been involved with the regulation and registration of pesticides for over 60 years. The Administration's proposed Federal Environmental Pesticide Control Act of 1971 attempts to strengthen controls, particularly to restrict harmful uses. In Febru-

ary 1972, the President initiated new programs to promote the concept of integrated pest management through increased research on new techniques, field testing and demonstrations, and development of programs for training crop protection specialists. These new programs and existing Federal efforts are aimed at developing a wide range of integrated pest management techniques and the manpower and institutional bases for their widespread adoption. Only through such development can we ultimately resolve the dilemma of providing adequate food for a burgeoning population and minimizing damage to the environment.

references

(1) Aldrich, Daniel, Jr. 1968. "World Food and Population Crisis." *Science* 162:1309–10.

(2) Andres, Lloyd A. 1971. "The Suppression of Weeds with Insects." In *Proceedings: Tall Timbers Conference on Ecological Animal Control by Habitat Management.* No. 3. Pp. 185–95.

(3) Anon. 1971. "Insect Hormone Mimics Near Market." *Chem. & Eng. News* 49:33–34. November 29.

(4) Anon. 1971. "Pheromones: Basis of Moth Control." *Chem. & Eng. News* 49:79–80. August 9.

(5) Baker, K.F., and Smith, S.H. 1966. "Dynamics of Seed Transmission of Plant Pathogens." *Ann. Rev. Phytopathol.* 4:311–34.

(6) Baker, K.F., and Snyder, W.C. (eds.). 1965. *Ecology of Soilborne Plant Pathogens.* Berkeley: University of California Press.

(7) Balch, R.E., and Bird, F.T. 1944. "A Disease of the European Spruce Sawfly, *Gilpinia hercyniae* (*Htg.*), and Its Place in Natural Control." *Sci. Agr.* 25:65–80.

(8) Beroza, Morton. 1972. "Attractants and Repellants for Insect Pest Control." In *Pest Control Strategies for the Future.* Washington: National Academy of Sciences. Pp. 226–53.

(9) Bird, F.T. 1953. "The Use of the Virus Disease in the Biological Control of the European Pine Sawfly, *Neodiprion sertifer* (*Geoffr.*)." *Can. Entomol.* 85:437–46.

(10) Borkovec, Alexej. B. 1966. *Insect Chemosterilants.* Vol. VII of Metcalf, R.L. (ed.). *Advances in Pest Control Research.* New York: Interscience Publishers.

(11) Borlaug, N.E. 1953. "New Approach to the Breeding of Wheat Varieties Resistant to *Puccinia graminis tritici.*" *Phytopathol.* 43:467 (abstr.).

(12) Brodie, Bill B., Good, J.M., and Jaworski, C.A. 1970. "Population Dynamics of Plant Nematodes in Cultivated Soil: Effect of Summer Cover Crops in Newly Cleared Land." *J. Nematol.* 2:217–22.

(13) Brown, A.W.A. 1968. "Insecticide Resistance Comes of Age." *Bull. Entomol. Soc. Amer.* 14:3–9.

(14) Brown, A.W.A., and Pal, R. 1971. *Insecticide Resistance in Arthropods.* Monogr. Ser. No. 38. Rome: World Health Organization.

(15) Burges, H.D., and Hussey, N.W. 1971. *Microbial Control of Insects and Mites.* London: Academic Press.

(16) Canada, Department of Agriculture. Information provided to the Council.

(17) Cooke, Roderic. 1968. "Relationships Between Nematode-Destroying Fungi and Soil-Borne Phytonematodes." *Phytopathol.* 58:909–13.

(18) Davidson, A.G., and Prentize, R.M. (eds.). *The Important Forest Insects and Diseases of Mutual Concern to Canada, the United States and Mexico.* Department of Forestry and Rural Development in Canada Pub. No. 1180.

(19) Debach, Paul. 1972. "The Use of Imported Natural Enemies in Insect Pest Management Ecology." In *Proceedings: Tall Timbers Conference on Ecological Animal Control by Habitat Management.* No. 3. Pp. 211–33.

(20) Dietrick, Everett J. 1972. "Private Enterprise Pest Management Based on Biological Controls." In *Proceedings: Tall Timbers Conference on Ecological Animal Control by Habitat Management.* No. 4. In press.

(21) Dietrick, Everett J. Unpublished data.

(22) Dowden, P.B., and Girth, H.B. 1953. "Use of a Virus Disease to Control the European Pine Sawfly." *J. Econ. Entomol.* 46:525–26.

(23) The Federal Insecticide, Fungicide, and Rodenticide Act, ch. 125, 61 Stat. 163 (June 25, 1947), *as amended* 7 U.S.C. §§ 135 et seq.

(24) The Federal Insecticides Act, ch. 191, 36 Stat. 335 (Apr. 26, 1910).

(25) Glaser, R.W., and Chapman, J.W. 1913. "The Wilt Disease of Gypsy Moth Caterpillars." *J. Econ. Entomol.* 6:479–88.

(26) Good, J.M. 1972. "Management of Plant Parasitic Nematode Populations." In *Proceedings: Tall Timbers Conference on Ecological Animal Control by Habitat Management.* No. 4. In press.

(27) Good, J.M. 1968. "Relation of Plant Parasitic Nematodes to Soil Management Practices." In Smart, Grover C., Jr., and Perry, V.G. (eds.). *Tropical Nematology.* Gainesville: University of Florida Press.

(28) Hansberry, Roy. 1968. "Prospects for Nonchemical Insect Control—An Industrialist's View." *Bull. Entomol. Soc. Amer.* 14:229–35.

(29) Hanson, A.A. 1971. "A Directed Ecosystem Approach to Pest Control and Environmental Quality." *J. Environ. Qual.* 1: 45–54.

(30) Hartman, Ronald C. 1971. "Biological Fly Control Spreads." *Poultry Dig.* Pp. 224–27. May.

(31) Heimpel, A.M. 1965. "Microbial Control of Insects." *World Rev. Pest Control* 4(4): 150–61.

(32) Hickey, J.J., Keith, J.A., and Coon, F.B. 1966. "An Exploration of Pesticides in a Lake Michigan Estuary." *J. Appl. Ecol.* 3 (suppl.): 141–54.

(33) Hoffman, C.H. 1971. "Restricting the Use of Pesticides—What Are the Alternatives?" In *Economic Research on Pesticides for Policy Decision Making.* Washington: Department of Agriculture, Agricultural Research Service. Pp. 21–30.

(34) Jensen, N.F. 1952. "Population Variability in Small Grains." *Agron. J.* 57: 153–62.

(35) Johnson, H.W. 1972. "Development of Crop Resistance to Diseases and Nematodes." *J. Environ. Qual.* 1(1): 23–27.

(36) Knipling, E.F. 1971. Statement presented before the Senate Committee on Agriculture and Forestry, Subcommittee on Agricultural Research and General Legislation. Sept. 30.

(37) Knipling, E.F. 1968. "The Potential Role of Sterility for Pest Control." In LaBrecque, Germain C., and Smith, Carroll. *Principles of Insect Chemosterilization.* New York: Appleton-Century-Crofts. Pp. 7–40.

(38) LaChance, L.E., Schmidt, C.H., and Bushland, R.C. 1967. "Radiation-Induced Sterilization." In Kilgore, Wendell W., and Doutt, Richard L. (eds.). *Pest Control: Biological, Physical and Selected Chemical Methods.* New York: Academic Press. Pp. 147–96.

(39) Luginbill, Philip, Jr. 1969. "Developing Resistant Plants—The Ideal Method of Controlling Insects." Product Res. Rep., No. 111. Washington: Department of Agriculture, Agricultural Research Service.

(40) Mai, W.F. (Chr., Subcom.). 1968. *Control of Plant Parasitic Nematodes.* Vol. 4 of *Principles of Plant and Animal Pest Control.* Pub. No. 1696. Washington: National Academy of Sciences.

(41) McClellan, W.D., Department of Agriculture, Agricultural Research Service. 1971. "History of Research by the U.S. Department of Agriculture on Domestic and Foreign Pests Emphasizing the Development of Biological and Other Alternative Methods of Control." (mimeo)

(42) Newsom, L.D. 1970. "The End of an Era and Future Prospects for Insect Control." In *Proceedings: Tall Timbers Conference on Ecological Animal Control by Habitat Management.* No. 2. Pp. 117–36.

(43) The Occupational Safety and Health Act of 1970, P.L. 91–595, 91st Cong., 2d Sess. (Dec. 29, 1970), codified at 5 U.S.C. §§ 5108, 5314, 5315, 7902, 15 U.S.C. § 663, 636, 18 U.S.C. § 1114, 29 U.S.C. §§ 553, 651–78, 42 U.S.C. § 3142–1, 49 U.S.C. § 1421.

(44) Painter, Ruth R. 1967. "Repellents." In Kilgore, Wendell W., and Doutt, Richard L. (eds.). *Pest Control: Biological, Physical and Selected Chemical Methods.* New York: Academic Press. Pp. 267–85.

(45) Pimentel, David. 1972. Information provided to the Council.

(46) Pimentel, David. 1972. "Pesticides, Pollution and Food Supply." Compilation of Department of Agriculture data. Submitted to *Bioscience.*

(47) Presley, John T., and Bird, Luther S. 1968. "Diseases and Their Control." In Elliot, Fred C., Hoover, Marvin, and Porter, Walter K., Jr. (eds.). *Advances in Production and Utilization of Quality Cotton: Principles and Practices.* Ames: Iowa State University Press. Pp. 347–66.

(48) Rincon-Vitova Insectaries, Inc. 1972. Information provided to the Council.

(49) Robbins, W.E. 1972. "Hormonal Chemicals for Invertebrate Pest Control." In *Pest Control Strategies for the Future.* Washington: National Academy of Sciences. Pp. 172–96.

(50) Rudd, R.L. 1971. "Pesticides." In Murdoch, William W. (ed.). *Environment: Resources, Pollution and Society.* Stamford, Conn.: Sinauer Associates. Pp. 279–301.

(51) Ruud, Louis A., Jr., California Agricultural Services, Kerman, Calif. 1972. Information provided to the Council.

(52) Sanford, G.B. 1959. "Root Disease Fungi as Affected by Other Soil Organisms." In Holton, C.S. (ed.). *Plant Pathology, Problems and Progress 1908–1958.* Madison: University of Wisconsin Press. Pp. 367–76.

(53) Smith, R.F. 1970. "Pesticides: Their Use and Limitations in Pest Management." In *Concepts of Pest Management.* Raleigh: North Carolina State University. Pp. 103–18.

(54) Smith, R.F., and Van den Bosch, Robert. 1967. "Integrated Control." In Kilgore, Wendell W., and Doutt, Richard L. (eds.). *Pest Control: Biological, Physical and Selected Chemical Methods*. New York: Academic Press. Pp. 295–340.

(55) Sprague, G.F., and Dahms, R.G. 1972. "Development of Crop Resistance to Insects." *J. Environ. Qual.* 1(1):28–34.

(56) Stanford Research Institute. 1972. *Environmental Indicators for Pesticides*. Contract report to the Council on Environmental Quality. Based on U.S. Tariff Commission and Census Bureau figures. NTIS Order No. PB 210–666.

(57) Stevens, R.B. 1960. "Cultural Practices in Disease Control." In Horsfall, J.G., and Dimond, A.E. (eds.). *Plant Pathology, an Advanced Treatise*. Vol. 3. New York: Academic Press.

(58) Strong, Richard D., California Farm Bureau Federation. 1971. Cited in Smith, Ray F. "Solutions to Problems Associated with Agricultural Chemicals: What Is Being Done by the Universities." (mimeo)

(59) Suneson, C.A. 1960. "Genetic Diversity—A Protection Against Plant Diseases and Insects." *Agron. J.* 53:319–21.

(60) United Nations, Food and Agriculture Organization. 1968. *The State of Food and Agriculture*. Rome: Food and Agriculture Organization.

(61) U.S. Department of Agriculture. 1972. Information provided to the Council.

(62) U.S. Department of Agriculture. 1971. "Scouting Cotton Insects Increases Profits and Reduces Insecticides." *News*. Oct. 4.

(63) U.S. Department of Agriculture. 1970. *Selected Weeds of the United States*. Agricultural Handbook No. 366. Washington: Government Printing Office.

(64) U.S. Department of Agriculture. 1967. *Agricultural Statistics*. Washington: Government Printing Office.

(65) U.S. Department of Agriculture, Economic Research Service. 1972. Information provided to the Council.

(66) U.S. Department of Agriculture, Economic Research Service. 1970. *Quantities of Pesticides Used by Farmers*. Agr. Econ. Rep. No. 179. Washington: Government Printing Office.

(67) U.S. Department of Agriculture, Economic Research Service. 1968. *Extent of Farm Pesticide Use on Crops in 1966*. Agr. Econ. Rep. No. 147. Washington: Government Printing Office.

(68) U.S. Department of Agriculture, Forest Service. 1972. Information provided to the Council.

(69) U.S. Department of Health, Education, and Welfare. 1969. *Report of the Secretary's Commission on Pesticides and Their Relationship to Environtal Health*. Parts I and II. Washington: Government Printing Office.

(70) U.S. President's Science Advisory Committee. 1965. *Restoring the Quality of Our Environment: Report of the Environmental Pollution Panel, President's Science Advisory Committee*. Washington: The White House.

(71) Van den Bosch, Robert, and Stern, V.M. 1969. "The Effect of Harvesting Practices on Insect Populations in Alfalfa." In *Proceedings: Tall Timbers Conference on Ecological Animal Control by Habitat Management*. No. 1. Pp. 47–54.

(72) Walker, J.C. 1957. *Plant Pathology*. New York: McGraw-Hill Book Co., Inc.

(73) Young, Roy A. (Chr., Subcom.). 1968. *Principles of Plant and Animal Pest Control*. Vol. 1 of *Plant Disease Development and Control*. Pub. No. 1596. Washington: National Academy of Sciences.

(74) Zoecon Corporation. Information provided to the Council.

appendix contributors

The following individuals and organizations served a major role in advising the Council on Environmental Quality on integrated pest management.

Mr. Everett J. Dietrick
Rincon-Vitova Insectaries
Riverside, California

Dr. R. L. Doutt
Division of Biological Control
University of California, Berkeley
Berkeley, California

Dr. Louis Getzin
Western Washington Research and Extension Center
Puyallup, Washington

Dr. Lawrence Gilbert
Department of Biology
Northwestern University
Evanston, Illinois

Mr. C. H. Musgrove
Specialist, Integrated Citrus Pest Management
Riverside, California

Dr. L. Dale Newsom
Department of Entomology
Louisiana State University
Baton Rouge, Louisiana

Mr. John Nickelsen
Association of Applied Insect Ecologists
Shafter, California

Dr. Richard Norgaard
Department of Agricultural Economics
University of California, Berkeley
Berkeley, California

Dr. David Pimentel
Department of Entomology
Cornell University
Ithaca, New York

Dr. Paul Santelmann
Department of Agronomy
Oklahoma State University
Stillwater, Oklahoma

Dr. Robert van den Bosch
Division of Biological Control
University of California, Berkeley
Berkeley, California

Representatives from:

Department of Agriculture

Department of Defense

Department of Health, Education, and Welfare

Department of the Interior

Environmental Protection Agency

National Canners Association

Niagara Chemical Company

Office of Management and Budget

Office of Science and Technology

U.S. GOVERNMENT PRINTING OFFICE: 1972 O—464-590